An Investigation into the Psychological Determinants of Health Habit Formation

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Statement of own work

I, Gabrielle Judah, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Gabrielle Judah

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Abstract

Forming habits – broadly defined as learned automatic responses to contextual cues – is proposed as a means to health behaviour maintenance. Habits form through context dependent repetition, but additional variables may affect this process. This work aimed to investigate additional predictors of habit formation.

The potential predictors investigated were: placement in a routine; attraction versus health information; perceived reward and its impact; and individual differences.

The study investigated habit formation for dental flossing and taking a vitamin C tablet daily, in a sample of 118 participants from the general public. Eighty participants received an online intervention for vitamin C tablets at the start of the study. All participants received an intervention for flossing after four weeks, randomised to be based on attraction versus health, and to advise flossing before or after brushing. Self-reported behaviour, habit, and motivational variables were measured every four weeks, for sixteen weeks.

Habit strength and behaviour increased for both target behaviours. Neither behaviour nor automaticity were affected by the attraction and health interventions, or placement of flossing before or after toothbrushing. Experiencing the behaviour to be rewarding led to greater automaticity, but was not mediated by behaviour frequency. Reward strengthened the behaviour-automaticity relationship, as predicted by theories of reinforcement. Pleasure and intrinsic motivation also acted in this way, but positive attitudes about the behavioural outcomes did not predict behaviour or automaticity. Rational, rather than experiential, thinking style was associated with weaker habits, and higher prospective memory ability predicted greater initial gains in behaviour, followed by stronger habits.

The results suggest that there are experiential and trait factors which affect the habit formation process and which can reinforce habits, beyond their impact upon repetition. These findings advance habit theory and lead to suggestions for intervention development, such as recommending encouraging intrinsic motivation, and tailoring interventions according to individual dispositions.

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Chapter 1: Literature Review

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1.1 Glossary

Habit: Learned automatic associations between a situation and a behavioural response

Reward: The positive value that an individual ascribes to an object, behavioural act or an internal physical state

Event: a sequence of actions that are conceptually related, in fulfilling the same goal, or taking place at the same location

Event boundary: the transition period between two events

1.2 Importance of habit formation to health

The vast majority of current major health problems are associated with the regular performance of unhealthy behaviour (e.g. over-eating, smoking, drug use) or a lack of uptake of healthier options (e.g. doing exercise, taking medicines appropriately, wearing seat-belts) (Curtis & Aunger, 2011). Performing unhealthy behaviours or failing to adopt healthy behaviours have been linked to around half of all deaths in the US (Danaei et al., 2009), and are associated with greater than a three-fold increased risk of mortality of older adults in Europe (Haveman-Nies, 2002). However, despite the obvious public health benefit of being able to change behaviour, it is notoriously difficult to do so, with initial gains in behaviour often being lost over time (Jeffery et al., 2000; Kumanyika et al., 2000; Marcus et al., 2006; McCaul, Glasgow, & O'Neill, 1992).

Habits have been cited as a means of providing sustainable behaviour change, ensuring maintenance of the behaviour, rather than simply initiation of a new behaviour (Nilsen, Gardner, & Broström, 2013; Rothman, Sheeran, & Wood, 2009; Rothman, 2000). Habitual behaviours are often characterised as those which have been frequently performed, in a stable context, such that behaviour proceeds with a high degree of automaticity. Several different behaviours relevant to health are claimed to be habitual, or demonstrated to be predicted by habit, such as handwashing with soap (Aunger et al., 2010), toothbrushing (Aunger, 2007), medication adherence (Bolman, Arwert, & Vollink, 2011; Phillips, Leventhal, & Leventhal, 2012; Ruppar & Russell, 2009; Stawarz, Cox, & Blandford, 2014b), doing exercise (Aarts, Paulussen, & Schaalma, 1997; Gardner, de Bruijn, & Lally, 2011), fruit consumption (de Bruijn, Wiedemann, & Rhodes, 2013), and even clinical behaviour (Gardner, Lally, & Wardle, 2012; Nilsen, Roback, Brostrom, & Ellstrom, 2012). However, many new target behaviours would need to be inserted into already automatic sequences of behaviour, with the consequence that good intentions have little impact; this makes changing behaviour, and forming new habits, a difficult endeavour.

Nevertheless, once new behaviours are habitual, it is likely that they will continue to be performed, providing the context remains stable (Wood, Tam, & Guerrero Witt, 2005). This is because performance will no longer rely very heavily on remembering the behaviour, or on strong motivations to perform it. This sustainability indicates that habit formation should be a goal of behaviour change interventions.

Many programs tend to focus on initiation only, through a tendency to look at short term changes in behaviour. There is evidence that focussing on habit formation in behaviour change interventions is an effective way to change behaviour (McGowan et al., 2013).
In this context, this research will investigate potential predictors of habit formation.

1.3 Summary of habits

1.3.1 An old concept

While the idea of habit and behaviour repetition leading to automaticity is often traced back to William James (James, 1890), the concept is actually much older than that. Aristotle considered that consistent patterns of good choices, or habits, leads to virtue (Miller, 1974). Discussion of the effect of habit on behaviour can also be found in the fourth and fifth centuries in the Jerusalem Talmud (a Jewish religious text). There is a debate about whether someone needs to repeat a prayer (which is to be said three times daily) if they cannot remember whether they included or omitted a passage which is added to the prayer during the winter months. The conclusion was that within thirty days of the change, if you forgot whether or not you said the extra passage, you are likely to have erred due to the force of habit (Jerusalem Talmud, Taanis 3b). However, after that time period, the rabbis held that one is likely to have said the prayer correctly, due to the assumption that the new habit, as opposed to the old one, is being acted upon. Therefore the prayer need not be repeated. There is also debate about whether it is the duration of time or the number of repetitions which is important. Despite the intuition with which thinkers so long ago recognised some key features of habit, it is only in recent years that psychologists have turned their minds to the precise mechanisms of habit formation in people.

1.3.2 Definition of habits

Habits have been described in several different ways in the literature, from frequently performed behaviour that becomes automatically activated on encountering the relevant cues (Orbell & Verplanken, 2010; Verplanken, 2006; Wood & Neal, 2007; Wood & Neal, 2009), to stimulus-response associations which persist even when the reward has been devalued (Adams, 1982; Adams & Dickinson, 1981; Dickinson, 1985; Killcross & Coutureau, 2003), to

automatic goal directed action (Aarts & Dijksterhuis, 2000; Bargh, 1994; Bargh & Chartrand, 1999; Danner, Aarts, Papies, & de Vries, 2011).

Common features of various theories of habit in humans are that habits are behaviours which are frequently repeated, and have reached a high degree of automaticity (Orbell & Verplanken, 2010; Wood & Neal, 2009). Most definitions include a focus on automaticity, and it can be argued that the key component of habit is automaticity (Gardner, 2012; Lally & Gardner, 2013). However the precise role of automaticity varies between different accounts of habits.

The first area of distinction is whether or not habits are seen as being goal-directed. One view is that habits are goal-directed automatic behaviours (Aarts & Dijksterhuis, 2000; Bargh & Chartrand, 1999; Danner et al., 2011). That is to say, habits are described as mental associations between goals (such as eating lunch) and the behaviour instrumental for achieving that goal (such as having a sandwich) (Aarts & Dijksterhuis, 2000; Sheeran, Webb, & Gollwitzer, 2005). However, studies which test the association between goals and behaviour in this way, often fail to compare this association with that between the context and behaviour. (When, on occasion, the context is considered, it is the context associated with the goal, as opposed to the context that might be expected to cue the behaviour.)
An alternative view is that habitual behaviour is automatically cued by the context. This view is supported by a study comparing different types of association with priming tasks (using cues selected by the participants), which only observed a significant effect of recognising behaviour words more quickly with context cues, but not with goal cues (Neal, Wood, Labrecque, & Lally, 2012). Following priming with goals, only participants with moderately strong habits (as opposed to strong or weak habits) showed triggering of the habitual behaviour. This suggests that for strong habits, goals have less influence, and behaviour is cued by the context, independent of current goals. The definition of habitual behaviour as those cued by the context is consistent with the definition from the animal learning and neuroscience literatures of habits as stimulus-response associations (Robbins, Giardini, Jones, Reading, & Sahakian, 1990; Yin & Knowlton, 2006). Indeed, the association between a goal and the behaviour needed to achieve that goal, maps onto the response-outcome association within the animal learning literature - this is defined as instrumental learning and is distinct from habit learning. There is good reason, therefore, to say that habits should not be seen as goal-directed automaticity. This supports decisions to utilise a definition of habit which relates to the connection between a contextual cue and behaviour.

Another question raised in defining habit is whether it is seen as a psychological process which prompts behaviour, or an automatic behaviour in itself. A recent review of the definition of the term "habit" in reference to health behaviour found varying definitions, which were often not closely based on theory of habit (Gardner, 2014). The definitions included describing habit as a type of behaviour (Gardner, Abraham, Lally, & de Bruijn, 2012a; Gardner et al., 2011; Nilsen et al., 2012), or a tendency towards a behaviour (Ouellette & Wood, 1998). However, as the concept of habit is used to explain or predict behaviour, both these definitions were criticised as being tautologous, as a "habit cannot be both the behaviour and the cause of the behaviour" (Maddux, 1997), or be used to explain that an "individual tends to perform a behaviour because they have a tendency to perform the behaviour" (Gardner, 2014). A third definition in the literature portrays habit as a form of automaticity, whereby stable performance situations cue the behaviour (Verplanken & Wood, 2006; Wood & Neal, 2009), thus avoiding the problem above by describing habit as a cognitive mechanism rather than the behaviour itself. However, the review raises a different issue with this definition, due to the possible implication that the behavioural response necessarily follows the occurrence of the cue: but although it is challenging, it remains possible to inhibit habitual responses given sufficient willpower (Neal, Wood, & Drolet, 2013; Wood & Neal, 2009), goals or intentions (Holland, Aarts, & Langendam, 2006; Wood et al., 2005), or planning (Schwarzer & Luszczynska, 2008). However, descriptions within the animal literature, have described habit as the automatic activation of the *representation* of the response by the stimulus (de Wit & Dickinson, 2009; Dickinson, Nicholas, & Adams, 1983). The fact that the situational cue activates the representation of the response, rather than the response itself, means that in the absence of conflicting goals or intentions, the behaviour is likely to proceed effortlessly; however, in a situation with sufficient conflicting intentions or goals, the automatically activated habitual response can be inhibited. (The habit may therefore be thought of as lowering the threshold to the response.) As automaticity can justifiably be understood as not leading inevitably to the behaviour, habit will be defined here as a learned automatic association between a situation and a behavioural response (Verplanken & Wood, 2006; Wood & Neal, 2009).

Regardless of the specific definition of habit selected, there is consensus across the various viewpoints, that habits are predictive of behaviour (Aarts & Dijksterhuis, 2000; Hall & Fong, 2007; Hofmann, Friese, & Wiers, 2008; Ouellette & Wood, 1998), and therefore likely to be useful in promoting lasting behaviour change (Lally, Chipperfield, & Wardle, 2008; Rothman et al., 2009). Habit formation is thus universally considered to be an important area of research for promotion of healthy lifestyle behaviours.

1.3.3 Properties of habits

Habits are adaptive, as performing well-learned behaviours automatically means that cognitive and attentional resources can be freed up for other tasks, such as those which are novel or urgent (Norman & Shallice, 1986). Habits in macaque monkeys have been shown to form in order to reduce the effort involved in a particular task (Desrochers, Jin, Goodman, & Graybiel, 2010). The performance of habits can be understood in terms of dual process models (Wood, Labrecque, Lin, & Rünger, 2014). Several types have been described (Evans, 2008), but all include reference to automatic versus deliberative processes (Kahneman, 2003; Lieberman, Gaunt, Gilbert, & Trope, 2002; Strack & Deutsch, 2004). Habit can be seen as one type of fast, automatic response process (Evans, 2008).

Habits (in addition to past behaviour) have a direct impact upon future behaviour (Allom, Mullan, & Sebastian, 2013). A recent meta-analysis revealed that habits for nutrition and physical activity have a medium-strong correlation with behaviour, so habits are predictive of future behaviour (Gardner et al., 2011). The automatic nature of habits results in the finding that past behaviour and current habits are typically more predictive of future behaviour than intentions (Aldrich, Montgomery, & Wood, 2010; Danner, Aarts, & de Vries, 2008), including in a meta-analysis (Ouellette & Wood, 1998). Therefore, where habits conflict with deliberative intentions, behaviour tends to be guided by habit (Triandis, 1977). Eight of nine studies in the meta-analysis showed that the relationship between intention and behaviour weakens as habit strength increases (Gardner et al., 2011), indicating that when habits are stronger, intentions have less of an impact on behaviour (Allom et al., 2013; de Bruijn, 2010; de Bruijn et al., 2007; van Bree et al., 2013). However, there is also evidence showing the opposite relationship: that strong habits actually strengthen the intention-behaviour relationship with regards to binge drinking and strenuous physical activity (de Bruijn, Rhodes, & van Osch, 2012; Gardner, de Bruijn, & Lally, 2012; Rhodes & De Bruijn, 2010). However, these findings have been qualified by the authors. Strong correlations were observed between habits and intentions, resulting in limited data to assess the effect at strong intentions and weak habits (and vice versa), suggesting that the inferences made about these points may lack validity (Gardner, de Bruijn, et al., 2012). The observation that habit strengthens the intention-behaviour relationship for strenuous, but not for moderate, physical activity was interpreted to suggest that strenuous activity may rely on motivational in addition to automatic processes, rather than habitual processes dominating as in simpler behaviours (de Bruijn et al., 2012; Rhodes & De Bruijn, 2010).

Habits may persist even when no longer consistent with current motivations. For example, participants with a strong habit for eating popcorn in a cinema continue to do so even if they are eating stale popcorn and report not enjoying it (Neal, Wood, Wu, & Kurlander, 2011). Habits are also a better predictor of medication adherence than beliefs about the treatment (Phillips, Leventhal, & Leventhal, 2013), and attitudes towards water usage are poorer predictors of water consumption than habits (Gregory & Leo, 2003). The explanation for these findings is that habits are believed to result from repeated behaviour reinforcing the context-behaviour association, so that once habits have formed, when the relevant cues are encountered the behaviour proceeds independent of current motivations.

While habits are shown to persist, this is only so if the context remains stable (as would be expected from behaviour prompted by automatic stimulus-response associations). A correlational survey of students moving to a different university campus found that habitual behaviours (such as exercise and reading the news) persist if features of the context remain constant, but revert to intentional control if the context changes (Wood et al., 2005). Likewise, existing habits are disrupted at points of major life changes, such as getting married, moving house or changing jobs (Rothman et al., 2009; Verplanken, Walker, Davis, & Jurasek, 2008). Thus these major life changes can be seen as critical points at which existing habits are disrupted, and so in the absence of contextual cues, behaviour is more likely to be under intentional control, at least until new habits form (Bayley, Frascino, & Squire, 2005; Verplanken & Wood, 2006). Efforts to change intentions may therefore have a greater effect on behaviour at these points. Alternatively, efforts to change habitual behaviour can focus on changing the context, in order to disrupt the contextual cues (Prochaska & DiClemente, 1983; van't Riet, Sijtsema, Dagevos, & De Bruijn, 2011).

The fact that habitual responses are context-dependent, means that even if the behaviour proceeds with a high degree of automaticity, if the cue is infrequently encountered, the behaviour would be only rarely performed (Gardner, 2014). Therefore, if the performance of a habitual behaviour is disrupted by changing the context, the cue-response associations may remain as an 'implicit habit', which remains dormant until the relevant cues are again encountered. The old habitual behaviour would then be likely to occur following a return to the previous contexts, and so context changes may only provide a temporary change to habitual behaviour. An alternative view holds that if the habitual behaviour is not frequently performed, the underlying habit decays over time (Tobias, 2009).

The main consequence of these properties is that in the absence of major life changes, habitual behaviour is hard to alter using the usual strategies of changing intentions or motivation. Therefore, attainment of habits can be a goal for behaviour change interventions, in order to achieve more sustainable changes in behaviour (Rothman, 2000). For these interventions to be successful, habit theory should be considered, and methods used which are more likely to override existing habitual responses and accelerate formation of new habits.

1.4 How habits form

1.4.1 Summary

Despite the potential benefits of habit formation to health, few studies have investigated how habits form. One notable exception is a study which modelled the formation of a habit over time for eating, drinking or exercising behaviours. Participants self-selected a behaviour that was to be performed once daily in response to a salient cue, and reported behaviour and automaticity daily for 84 days. Automaticity was observed to increase according to an asymptotic curve, showing steep increases in automaticity following the intervention, which then was seen to plateau (Lally, van Jaarsveld, Potts, & Wardle, 2010). This pattern suggests that early repetitions of a behaviour have a bigger impact upon automaticity than later repetitions. There was considerable variation observed in the length of time participants took to reach their modelled asymptote level (18 to 254 days). The intervention was designed to achieve habit formation through "context-dependent repetition" (performing the behaviour in a consistent context) (Lally et al., 2008; Lally et al., 2010) which allows associations to form between the context and the behaviour, leading to habit formation.

An explanation for initial gains in behaviour following an intervention being lost over time is that different factors influence initiation and maintenance (Rothman et al., 2009; Rothman, 2000). Initiation requires positive expectations regarding outcomes of a particular behaviour, and maintenance requires perceived satisfaction with the experienced outcomes of the behaviour. Rather than just utilising interventions that are successful in promoting behaviour initiation, consideration should be given to the factors promoting maintenance in order to achieve sustainable behaviour change.

In a more detailed conceptual piece on how new habits are formed, this process is described as progressing through four stages (Lally & Gardner, 2013). Firstly, it is necessary for the

decision to be made to perform a new behaviour. This requires forming an intention, through trying to change predictors of intention (Ajzen, 1991; Fife-Schaw, Sheeran, & Norman, 2007; Webb & Sheeran, 2006). Secondly, the intention-behaviour gap must be overcome in order to translate the intention into action (Schwarzer & Luszczynska, 2008; Webb & Sheeran, 2006). This can be facilitated by using self-regulation strategies, such as planning (Michie, Abraham, Whittington, McAteer, & Gupta, 2009), or implementation intentions (Gollwitzer & Sheeran, 2006). Thirdly, this initiated behaviour must then be repeated, which is thought to require sustained motivation (Rothman et al., 2009). These first three steps are applicable to all behaviour change efforts. The fourth and final step, however, is exclusive to habit: the action should be repeated in a consistent context so that context-dependent automaticity (i.e. habit) may develop (Lally et al., 2010)).

While it is established that context-dependent repetition promotes habit formation (Lally et al., 2008; Lally et al., 2010; Wood & Neal, 2009), it was still observed that there is much variation in the time it takes for habits to form, and the eventual strength of those habits (Lally et al., 2010). The cause of this variation is unknown, suggesting that there are additional factors which affect how quickly habits form, and how strong they may become. This study attempts to identify some of the processes or predictors which lead from behaviour repetition to automaticity.

There has been little work to prospectively investigate further features of interventions that may promote habit formation (Sniehotta & Presseau, 2012). As well as factors which promote behaviour repetition leading to habit, there may be additional factors which reinforce behaviour by affecting the relationship between repetition and automaticity gain (de Wit & Dickinson, 2009). This has rarely been investigated in humans. Many studies have looked at variables which correlate with existing habits (de Bruijn et al., 2013; Rhodes, de Bruijn, & Matheson, 2010; Wiedemann, Gardner, Knoll, & Burkert, 2014). However, correlational studies have been criticised as leading to biased estimates, and as being unable to support decisions on intervention design (Weinstein, 2007). Many of the psychological constructs observed to correlate with behaviour, may have changed due to regular performance of the behaviour, and therefore may not have been the original cause of the behaviour performance. It has been observed that predictors of behaviour are seen to differ from predictors of behaviour *change* (Skår, Sniehotta, Araújo-Soares, & Molloy, 2008). As habits form from repeated behaviour, which was likely to be intentional, in the absence of an intervention to lead to counter-habitual intentions, habits and behaviours would be expected to correlate strongly given correlational designs (de Bruijn et al., 2012). Therefore, correlational studies are

limited in their ability to predict the relationship between intention, behaviour and habit, during the process of habit formation, or when intentions and habits conflict (Gardner, 2014).

In order for interventions to be developed which most effectively promote habits, studies must specifically investigate the formation of new habits following behaviour change interventions. Knowledge of features which reinforce behaviour could lead to design of behaviour change interventions which maximise the effect of each behavioural repetition on increases in habit. This would make habit formation more efficient, and increase the likelihood that behaviours come under automatic control before the effects of the initial intention and reminder wane (Tobias, 2009). The aim of the present research is to test the relevance of variables observed to correlate with existing habits, as well as other variables suggested by theory, in order to determine whether they play a role in the formation of new habits. Findings from such work may suggest constructs which should be included in intervention design, to facilitate the formation of new healthy habits.

The following sections now discuss in more detail the stages involved in habit formation, and predictors of success in forming habits.

1.4.2 Initiation

While this is a feature common to most behaviour change interventions, behavioural initiation is a vital first step in order to achieve maintenance and habit formation. While this is usually attempted through changing intention, a review of various different health behaviours observed that rates of performance from participants who intended to perform a particular behaviour were only 47% (Sheeran, 2002). Intentions have less impact upon changing regularly performed behaviours likely to be habits (Webb & Sheeran, 2006). Therefore, changing intentions alone is not sufficient to achieve changes in behaviour. Whether or not intentions are translated into action at the appropriate point is seen to depend on the salience, strength and stability of intentions (Sheeran, Orbell, & Trafimow, 1999).

Planning is an effective way to aid initiation, maintenance and habit formation (Fleig, Pomp, Parschau, et al., 2013; Schuz, Wiedemann, Mallach, & Scholz, 2009; Sniehotta, Soares, & Dombrowski, 2007). One key planning strategy for helping translate intentions into action is implementation intentions (Gollwitzer & Sheeran, 2006). These involve specifying if-then plans of the situation in which a behaviour is intended to occur and the behaviour itself, e.g. “When I encounter situation X, I will do behaviour Y”. Through setting up an association

between the situation and behaviour, when the specified situation is encountered, the behaviour is more likely to be performed. A meta-analysis demonstrated that implementation intentions are effective at translating intention to perform a new behaviour into action (Gollwitzer & Sheeran, 2006). As well as promoting initiation, implementation intentions were also seen to enhance the formation of a flossing habit after 4 weeks (Orbell & Verplanken, 2010). This effect was moderated by the goal strength for the behaviour.

In order to generate the most effective situational cues for implementation intentions, it may be helpful to consider what is known about prospective memory. This is defined as the ability to remember to do something at a future timepoint, or the "performance of delayed intentions" (McDaniel & Einstein, 2000). This is directly relevant to intentions to initiate a new behaviour in general, and to implementation intentions in particular. Therefore, knowledge about the function of prospective memory can help in achieving behaviour initiation.

The literature on prospective memory (PM) identifies different types of cues to assist in the performance of delayed intentions. These include time-based, event-based and activity-based prospective memory (McDaniel & Einstein, 2007). Event-based PM involves behaviour being cued by a feature of the environment, which could be seeing an object, place or another person (Einstein & McDaniel, 1990); activity-based PM requires identification of one's own actions (for example, taking a pill before or after dinner), and is generally described as being cued by the end of a certain activity (Harris, 1984; Kvavilashvili, Ellis, Brandimonte, Einstein, & McDaniel, 1996); and time-based PM requires performing an action at a specific time of day (Einstein & McDaniel, 1990; Harris, 1984).

When considering the type of cue most likely to prompt behaviour, time-based PM relies on self-initiated retrieval processes (reminding oneself to check the time), requiring cognitive control. Therefore time-based PM cues are harder to detect, and so are least likely to lead to behaviour becoming automatic, compared to event or activity-based PM (Stawarz, Cox, & Blandford, 2014a).

Activity-based PM is considered less demanding than either time or event-based PM because the external cue coincides with the end of an ongoing action and thus does not require interrupting a chain of activity (Kvavilashvili et al., 1996), unlike time- and event-based PM, where for example, one has to interrupt writing a paper to keep an appointment, or interrupt a journey to buy milk. Prior action cues are also likely to be more salient, and prompt an action only when it is relevant, compared with event-based cues, which may also be encountered at

times when the behaviour is not due to be performed. For this reason, it seems likely that implementation intentions for habit formation would be most effective if they specify a prior-action cue (e.g. "after arriving home from work") (Verplanken, 2005), due to increased salience, relevance, and less cognitive demand.

1.4.3 Maintenance – factors promoting repetition

Psychological predictors of maintenance

Different factors can predict maintenance of a new behaviour compared to initiation (Borland, 2010; Rothman, 2000). Decisions about initiation are held to be affected by whether a person expects beneficial outcomes from the new behaviour. However, the maintenance of a new behaviour depends on whether the outcomes experienced from the behaviour are considered sufficiently satisfying to justify the decision to continue performance (Rothman, 2000). There is also evidence that highly valued outcomes result in greater attention being paid to the cues associated with them (Le Pelley, Mitchell, & Johnson, 2013).

Studies on behaviours such as weight loss and smoking cessation have found that maintenance is associated with perceived satisfaction, or attribution of benefit to the outcomes (Baldwin et al., 2006; Baldwin, Rothman, & Jeffery, 2009; Klem, Wing, McGuire, Seagle, & Hill, 1997; Louro, Pieters, & Zeelenberg, 2007). Conversely, attributing greater costs associated with maintaining a diet (as opposed to the behavioural outcome) was seen to have a detrimental effect on long term compliance (Urban, White, Anderson, Curry, & Kristal, 1992).

Behaviour change attempts often focus on increasing knowledge of the health risks or benefits associated with a particular behaviour. However, despite widespread knowledge on the harms and benefits of various behaviours to health, levels of performance are still not optimal (Curtis, de Barra, & Aunger, 2011; Danaei et al., 2009). This suggests that increasing health knowledge is often not an effective way to motivate changes in behaviour (Zimmerman, Olsen, & Bosworth, 2000). It has been argued that human behaviour is driven by several basic motives, including social norms, attraction, disgust and comfort (Aunger & Curtis, 2013) which are argued to be better drivers of behaviour than health (Curtis & Aunger, 2011). Marketers have long been aware of the power of themes of attraction or sex, and often use these to sell products (Baker & Churchill Jr, 1977; Colarelli & Dettmann, 2003; Kahle & Homer, 1985; Till & Busler, 2000). This may be understood theoretically as health is based on more cognitive or

long term plans, but, attraction is a basic human motivation, so may drive behaviour in the shorter term. Recently, an intervention based on fundamental motives was shown to increase handwashing with soap in a rural Indian population (Biran et al., 2014). It has been observed that subtle reminders of companionate love increase the likelihood for healthy snack choices (Raska & Nichols, 2012), and it is suggested that social interaction improves dental hygiene practices (Choo, Delac, & Messer, 2001). In addition, it is theorised that emotion-inducing stimuli can elicit states of arousal (LeDoux, 1998; Schachter & Singer, 1962), and so emotions may have comparable psychological mechanisms to rewards (Schultz, 2002). Therefore, a focus on attractiveness, which could be emotion-inducing, may be an effective driver of behaviour change. However, the relative effectiveness of attractiveness and health knowledge on behaviour initiation and maintenance has not been well tested.

Effects on behavioural maintenance have been observed for variables from the Theory of Planned Behaviour (Ajzen, 1991), such as self-efficacy (Blanchard et al., 2007; Warziski, Sereika, Styn, Music, & Burke, 2008), social norms (Mosler & Kraemer, 2011; Mosler, 2012), and intentions (Inauen, Tobias, & Mosler, 2013), as well as the effect of perceived behavioural control on automaticity (de Bruijn et al., 2013). However, as not all of these studies included an intervention, it is not clear whether the theory of planned behaviour variables affect behaviour change as opposed to being correlates of existing stable behaviour. One habit formation study did show a direct effect of attitude on both flossing behaviour and automaticity: however the question of whether this was mediated by behaviour was not investigated (Judah, Gardner, & Aunger, 2012).

Reminders

Another challenge to behavioural maintenance, separate from that of satisfaction or maintenance, is that lack of success is caused primarily by forgetting (Tobias, Huber, & Tamas, 2013). This effect was investigated in a study modelling the habit formation process. The model was tested with reference to a behaviour change campaign about recycling behaviour in Cuba (Tobias, 2009), and found that following an intervention, behaviour levels are likely to be high, but subsequently decline over time. Visible reminders were observed to slow, but not prevent, the decline in behaviour, and so enhance the likelihood that performance of the behaviour may be sustained until habits form. The reason for decline of behaviour is attributed to the decreasing salience of intention over time leading to forgetting of the new behaviour, rather than a decision to about whether or not to continue performing the newly

initiated behaviour. The use of reminders can serve to avoid or delay failure of maintenance due to forgetting. In addition to visible reminders, reminders can take other forms, such as text messages, which have led to improved rates of physical activity (Prestwich, Perugini, & Hurling, 2009; Andrew Prestwich, Perugini, & Hurling, 2010; Webb, Joseph, Yardley, & Michie, 2010), or smartphone applications designed to give medication reminders tailored to individual routines (Stawarz et al., 2014a).

1.4.4 Automaticity gain – context-dependent repetition

Repeating a behaviour in a constant context is the route by which a behaviour becomes habitual, as through the strengthening of an association between a situation and behaviour (Dickinson, 1985), the situation subsequently cues the behaviour (Fleig, Pomp, Parschau, et al., 2013; Lally & Gardner, 2013). Therefore, if the situation is consistent, the association is more likely to be formed. This strategy has been utilised in habit formation studies (Lally et al., 2010; McGowan et al., 2013). An intervention to promote healthy child feeding habits including guidance on context-dependent repetition, showed increased behaviour and habits compared to a control group (McGowan et al., 2013), and linking taking of medication to a particular point in the daily routine is associated with better adherence (Stawarz et al., 2014b). After continued repetition, the different elements in a sequence of behaviours become linked together, or chunked (Graybiel, 1998; Terrace, 1991), so that following practice, what starts as variable, goal-directed action, becomes stable and rapidly performed (Dezfouli & Balleine, 2012). Therefore, through context-dependent repetition, behaviour performance can become more automatic due to connections forming between a sequence of actions.

Implementation intentions (Gollwitzer & Brandstätter, 1997) are commonly used to achieve initiation, but are also likely to promote context-dependent repetition. This is because planning the specific situation in which a behaviour should be performed, then adhering to this, is likely to lead to it occurring in that same situation, and therefore, a stable context.

A constant context may comprise features or cues that come to prompt habitual behaviour, such as place, prior behaviour, time of day, internal states, or other people (Wood et al., 2014; Wood & Neal, 2007). In a study looking at how exercise and newspaper reading habits changed for students moving to a different university campus, similarities in the behaviour of roommates and the proximity of sports facilities were seen to predict the sustaining of old habits when students moved to the new situation. The stability of context of habitual

behaviour has been assessed by measuring whether the behaviour is performed in the same place and time of day each time (Norman & Cooper, 2011).

Context-dependent repetition may be encouraged via strategies such as reminders (Pacini & Epstein, 1999; Prestwich et al., 2009; Prestwich et al., 2010; Webb et al., 2010), increasing the satisfaction with the outcome (Rothman, 2000), and instituting self-monitoring (Fleig, Lippke, Pomp, & Schwarzer, 2011; McGowan et al., 2013).

1.4.5 Additional potential predictors of automaticity

While context-dependent repetition is necessary for habit formation, it has been observed that even given a certain level of behaviour repetition, there is variation in the length of time taken for a habit to form (Lally et al., 2010). This implies that other factors may be important in the habit formation process. These may be related to the structure of routine behaviour, or the rewarding nature of the behaviour. Furthermore, individual trait differences may predict some variation in habit formation.

Structure of routine behaviour

While consideration has been given to the context in which a new behaviour is repeated, there has been less consideration of the structure of routine behaviour and whether certain points in a routine are more conducive to habit formation than others.

Many of our daily routine behaviours are considered to be hierarchical sequential routine action (Ruh, Cooper, & Mareschal, 2005). Basic level actions can be grouped into subsequences, which are in turn grouped into longer sequences, forming a hierarchy (Botvinick, Niv, & Barto, 2009). Levels in the hierarchy can be termed 'coarse grain events' (less detailed) or 'fine grain events' (more detailed) levels (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). For example, the script of getting ready in the morning could including the course grain action of getting dressed, which includes the fine grained actions of getting clothes out, putting each item of clothing on etc. (Zacks & Swallow, 2007; Zacks & Tversky, 2001; Zacks, Tversky, & Iyer, 2001). Sequences of events are chunked together (Graybiel, 1998) so that one behaviour cues the next.

An interesting feature in routine behaviour is the amount of awareness and mental processing that occurs at different points. Boundaries between events are associated with points of

change, such as of location, object use, or goal changes (Hard, Tversky, & Lang, 2006; Speer, Zacks, & Reynolds, 2007; Zacks, 2004). Consistency has been observed in the way that different people segment a series of events (Newtson, Engquist, & Bois, 1977). It has been observed in a virtual reality task that event boundaries are both harder to process, and require different processing resources, than steps within a segment (Ruh et al., 2005). When observing, or reading about behaviour, increased brain processing is detected at event boundaries than within an event (Fujii & Graybiel, 2003; Speer et al., 2007; Zacks, Braver, et al., 2001), indicating higher levels of cognitive control at event boundaries.

Event Segmentation Theory (EST) predicts these features of routine (Zacks et al., 2007), maintaining that when observing activity, people build mental models of the current situation which allows them to make predictions about perceptual input. These models remain constant until observed changes in the event reduce the accuracy of the current model predictions. This occurs at an event boundary. At this point, incoming perceptual information is again processed, and a new mental model is built. Active memory for current events is considered to be erased when the model is updated, so must instead be retrieved from long-term memory. There is evidence of difficulty retrieving information encountered prior to an event boundary (Gernsbacher, 1985; Speer & Zacks, 2005; Swallow, Zacks, & Abrams, 2009). If these features generalise from observation of behaviour to the processing of one's own behaviour, then this theory has implications for both the ability to initiate a new behaviour, and the tendency of that behaviour to become habitual. In particular, if prior-actions are being selected as cues to prompt a new behaviour, then those which span an event boundary may be less likely to be effective reminders, as they would be harder to retrieve. Additionally, due to more variation in sequence between course-levels events than for steps within the event, the cue may not be as reliably associated with the behaviour.

For these reasons, cues for a new behaviour may be expected to be more effective if they are selected from within the same event. An implication of this may be that if one attempts to insert a new behaviour at the beginning of an event using a prior action cue, the behaviour is less likely to be initiated, as the cue is more likely to occur at, or prior to an event boundary. This is illustrated in Figure 1 and Figure 2.

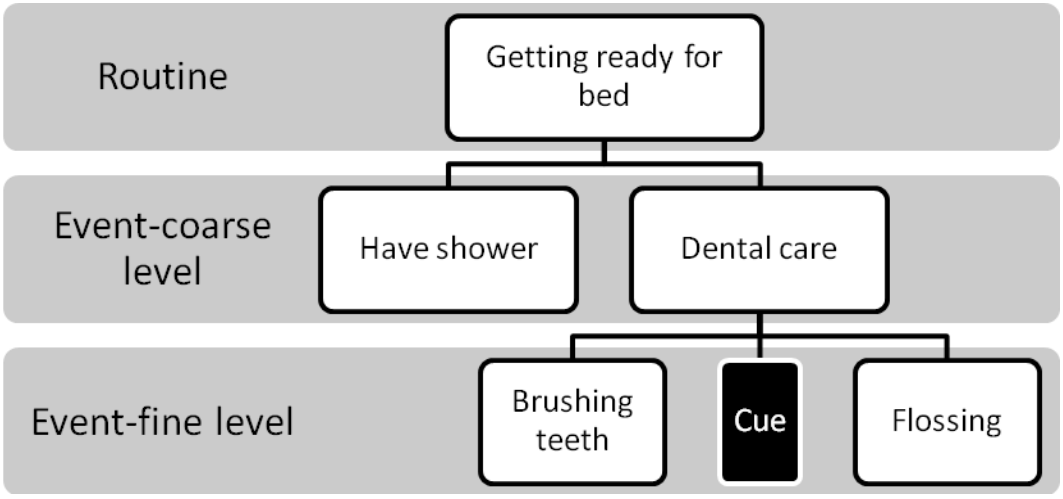

Figure 1 Adding flossing after toothbrushing
The prior-action cue occurs within the same course-level event as the new behaviour.

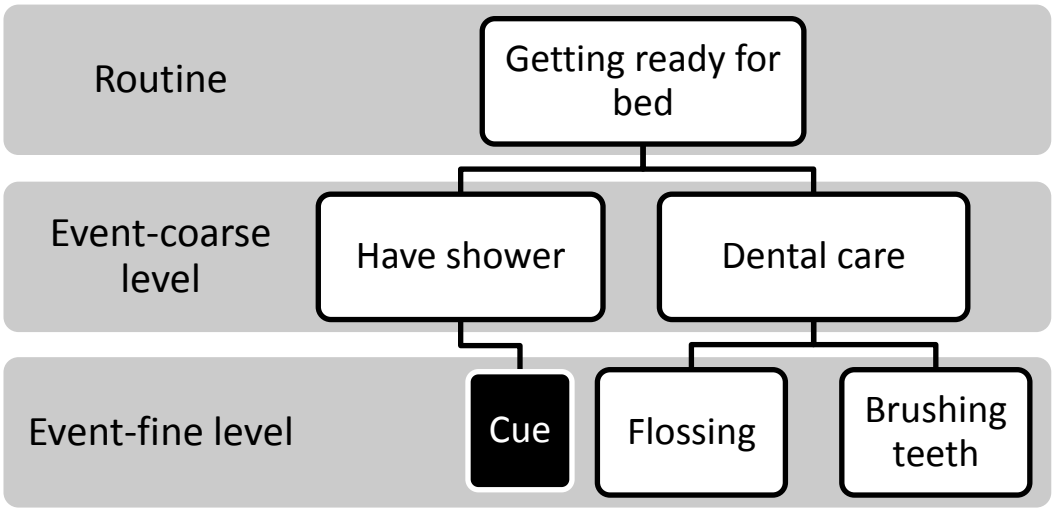

Figure 2 Adding flossing before toothbrushing
The prior-action cue occurs in the previous event to the new behaviour. (The other fine-level events have been omitted from the shower event for the sake of clarity; the cue should be assumed to be an action at the end of this cluster.)

In addition, the increased processing found at event boundaries may mean that there is increased awareness, which may result in a behaviour inserted at this point in a routine to be less likely to subsequently become habitual. Prior work on this issue demonstrated a tendency that people who were assigned to floss after, compared to before, brushing showed higher levels of behaviour and stronger habits (Judah et al., 2012). However, there was only a tendency towards higher habits at the end of the four week study and no effect of flossing placement on behaviour, as opposed to the significant effect observed at eight month follow up. The study suggests that placement in a routine may impact upon habit formation, as may be expected from Event Segmentation Theory (Zacks et al., 2007). However the study only had

a limited sample size, and monitored behaviour over the relatively short timeframe of four weeks. A more robust study design may help to determine the effect of placement in a routine upon behaviour repetition and habit. Knowledge of the impact of placement within a routine on likelihood of behavioural uptake and habit formation would be helpful in assisting interventions designed around maximising the likelihood of the new behaviour being sustained.

Rewards

Satisfaction increases the chance that a new behaviour will be repeated (Rothman, 2000), however it may be possible that satisfaction, or perceived reward may have a stronger role in promoting habit formation. According to the animal learning literature, it is the effect of the reward, not just the repeated co-occurrence of the stimulus and behaviour, which strengthens the association between the situation and response (Adams, 1982; de Wit & Dickinson, 2009; Dickinson, 1985).

Despite the key role played by reward in the animal habit literature, there has been little consideration of reward so far in research on human habit formation (aside from some studies of consumer behaviour (Lal & Bell, 2003; Taylor & Neslin, 2005; Wood & Neal, 2009)). It is useful to distinguish between intrinsic or perceived rewards, as opposed to extrinsic or tangible rewards, such as incentives (Deci, Koestner, & Ryan, 1999). In the animal literature, rewards are extrinsic: however, in human habit formation, both can be considered.

Intrinsic rewards are often held to be more effective at promoting sustained changes in behaviour (Ryan & Deci, 2000). One reason may be because with extrinsic rewards, the behaviour is potentially being performed with the expectation of the incentives (Colwill & Rescorla, 1985), with the result that performance remains goal-directed rather than becoming habitual. Therefore, the behaviour is more likely to cease or decrease once the reward is no longer provided, as observed in consumer behaviour (Kivetz, Urminsky, & Zheng, 2006; Wood & Neal, 2009). Therefore, if extrinsic rewards are used, they are more likely to lead to habit formation if achieving the reward does not become the goal of performing the behaviour (Dickinson, 1985), and so if there is less awareness of the connection between the behaviour and reward, for example, by using rewards which seem random in size and timing (Wood & Neal, 2009).

The effects of extrinsic rewards, or incentives (such as money or vouchers) have been investigated for behaviours such as smoking cessation (Dallery, Glenn, & Raiff, 2007), and

weight loss (Jeffery, 2012). These have not looked at automaticity per se, but have investigated the effects of incentives on behavioural maintenance. The effects of contingent and non-contingent rewards have also been investigated (Higgins et al., 2004). However, even amongst the reviews, results of long term effectiveness of incentives has been inconclusive (Cahill & Perera, 2008; Giles, Robalino, McColl, Sniehotta, & Adams, 2014; Kane, Johnson, Town, & Butler, 2004; Paul-Ebhohimhen & Avenell, 2008; Sutherland, Christianson, & Leatherman, 2008; Wall, Mhurchu, Blakely, Rodgers, & Wilton, 2006), possibly due to substantial variations between different studies (Adams, Giles, McColl, & Sniehotta, 2013).

However it is delivered, the presence of extrinsic rewards may reduce intrinsic motivation (Deci et al., 1999). They are also, by definition, costly. Therefore, greater consideration will be given to intrinsic rewards. The positive value ascribed to a reward leads it to reinforce behaviour. This reinforcement can strengthen associations and therefore lead to automaticity gain. What may count as a reward, aside from extrinsic incentives, is not clear, but various aspects could be investigated. Options include immediate sensory reactions, or pleasure, being intrinsically motivated for the behaviour, or satisfaction with the outcome of the behaviour.

Pleasure can be understood as immediate, positive sensory outcomes, and is a close analogue with the food or drug rewards used in animal literature. As habit uses comparable brain regions between humans and animals (Balleine & O'Doherty, 2009), it may be expected that physical pleasure will also serve as a reward in human habit formation.

There is evidence that **intrinsic motivation** is more likely to lead to stronger intentions and sustained changes in behaviour than extrinsic motivation (Biddle, Soos, & Chatzisarantis, 1999; Daley & Duda, 2006; Deci & Ryan, 2002; Silva et al., 2011), and this has also been investigated with reference to habits. Behaviour frequency was seen to be more predictive of exercise habit strength among more autonomously motivated participants (Gardner & Lally, 2013). An unexpected direct effect of self-determined regulation on automaticity was also observed, independent of past behaviour. Intrinsic motivation was seen to be associated with fruit consumption habits, both mediated by past behaviour, and by strengthening the relationship between behaviour and automaticity (Wiedemann et al., 2014). This moderation effect is consistent with the predictions of the Associative Cybernetic model (de Wit & Dickinson, 2009), and animal learning in general, where rewards are held to reinforce behaviour. However, these studies did not look at habit formation, so it is not clear whether intrinsic motivation works as a reward as habits are forming. They do nevertheless suggest that intrinsic motivation may be an important feature to investigate when studying habit formation.

Satisfaction with outcomes may be another potential feature of interest regarding reward, as it is seen to predict maintenance of a behaviour (Baldwin et al., 2006; Klem et al., 1997; Rothman, 2000). This is less immediate than the hypothesised rewards of pleasure or intrinsic motivation. However, as humans are more cognitive, and demonstrate greater planning abilities, it may be expected that longer term factors might have a role to play in human habit formation. Indeed, previous work suggests that factors such as attitude may directly impact upon habit formation, independent of behaviour repetition (Judah et al., 2012). It is thought that acting in a way consistent with **perceived positive outcomes** may be rewarding, and therefore reinforce the behaviour and lead to greater increases in automaticity per behaviour repetition.

In terms of the mechanism of habit formation, consideration of reward in this way would mark a shift in the investigation of human habit formation. Currently, habit formation is thought to be predicted by context-dependent repetition, and so anything that is rewarding and promotes repetition in a constant context is considered to have an effect on automaticity mediated by repetition (Lally et al., 2010; Wood & Neal, 2009). Animal models of habit formation (S. de Wit & Dickinson, 2009), and studies of existing habits in humans (Gardner & Lally, 2013; Wiedemann et al., 2014), show a reinforcement of behaviour through rewards increasing the impact of each repetition on automaticity. The present study may serve to establish whether this reinforcement is also seen in studies of human habit formation. Investigation of the mechanism of reward in habit formation, and what might reinforce behaviour, would have the benefit of helping to identify ways to maximise the impact of each behaviour repetition on development of a habit.

Individual differences in behaviour change and habit formation

Overview

Some variation in habit formation may be due to differences in individual traits, which may predict differences in initiation, behavioural repetition, or automaticity gain. It has long been considered that dispositional factors can affect the likelihood of both behavioural initiation and maintenance (Scheier & Carver, 1985). More recently, there is evidence of individual differences in associative learning (Byrom, 2013). Brain imaging data in humans has demonstrated that corticostriatal connectivity can explain individual differences in the tendency to habitual or goal-directed control of action (de Wit, Watson, et al., 2012). There is

both behavioural and neurological evidence that people with alcohol dependency show increased activation in brain areas associated with habit learning compared to controls, and less activation in areas associated with instrumental learning (Sjoerds et al., 2013). Accordingly alcohol dependent patients display more habitual, compared to instrumental, responses. Rats which show more acetylcholine release in the hippocampus, compared to the dorsal striatum, are more likely to show instrumental learning (goal directed), as opposed to stimulus-response habit learning. Neurological distinctions such as this may explain individual differences within habit formation (McIntyre, Marriott, & Gold, 2003).

However, these neurological correlates are not easily measured, so cannot be used to predict success in forming new habits. However, according to Pavlovian theory, temperament types lead to individual differences within habit formation (Windholz, 1998). Furthermore, dispositional tendencies which relate to the potential predictors or features of behaviour and habit formation described above, may impact upon the process accordingly. Knowledge of any dispositional features related to habit formation would aid both prediction of habit formation, and targeting and design of interventions. It would also provide insights for the theory of habit formation.

Prospective memory

The act of initiating a new behaviour is closely related to prospective memory. Prospective memory ability is known to vary across individuals (Brewer, Knight, Marsh, & Unsworth, 2010; Cherry & LeCompte, 1999). This ability is likely to impact upon behaviour repetition at early stages following an intervention, and was found to be related to levels of behaviour over four weeks following a flossing intervention (Judah et al., 2012). The impact of this could be investigated, to see if there is a benefit of better prospective memory ability on early behaviour repetitions, and therefore to see if this affects subsequent habit formation. The implication of this would be to advise providing additional reminder support (Tobias, 2009) for people who have poorer prospective memory ability.

Personality

Another feature that has previously been considered in the habit literature is the effect of personality measured using the Big 5 on the tendency to perform habits (Wood, Quinn, &

Kashy, 2002). No effects were observed here, yet this was a study of existing habits rather than one looking at habit formation. Personality traits have been understood to be biologically based dimensions of temperament (Strelau, 1998), and to be stable over time (Clark & Watson, 1999; Derryberry & Reed, 1994). Other behaviours which may be considered to be habits, such as smoking, gum chewing and compulsive buying are associated with the personality traits of high neuroticism and extraversion (Bivens, Gore, & Claycomb, 2013; Malouff, Thorsteinsson, & Schutte, 2006; Smith, 2009). Conscientiousness describes the tendency to be self-controlled and orderly, which may be expected to confer an advantage during behaviour initiation and repetition (Roberts, Jackson, Fayard, Edmonds, & Meints, 2009). It is not clear whether these traits are associated with behavioural maintenance, existing habits or formation of new habits. This will be tested in the present study.

Personal Need for Structure

Performing a behaviour in a constant context is a precursor of habit formation (Lally et al., 2010). Some people tend to have more structured and stable lives in general, or follow routines more rigidly (Giovannetti, Schwartz, & Buxbaum, 2007a). This would result in a greater likelihood of regularly encountering the cue which prompts the new behaviour, and performing the behaviour in a consistent context. Therefore, not only would it be easier to initiate a new behaviour due to effective cueing, but habits should also form more quickly than if a rigid script is not followed as a consistent cue will be more regularly paired with the behaviour. This tendency may be assessed using scales such as the Personal Need for Structure (Neuberg & Newsom, 1993). This trait was not observed to be predictive of habit in a previous study (Wood et al., 2002), though a study of formation may be a better test of this prediction.

Rational or Experiential style

Habitual behaviour can be understood as being related to the automatic rather than the reflective system (Wood et al., 2014). Rational thinking style has been described as logical, deliberate, cognitive, as showing slower processing, and is related to the reflective system. Experiential thinking style has been described as associative, automatic rapid and unconscious, and is related to the automatic system. Doctors who showed a preference for experiential rather than rational thinking style were observed to have higher hand hygiene compliance (Sladek, Bond, & Phillips, 2008). As handwashing with soap is thought to be a strongly habitual

behaviour (Aunger et al., 2010), this suggests that experiential thinking may be associated with a greater tendency to form habits. Consistent with this, a tendency to have stronger habits in a variety of behaviours was seen to be negatively associated with need for cognition (Wood et al., 2002). The relative dominance of the two modes of thinking has been shown to be related to relatively stable dispositional and situational factors (Epstein, 1994; Pacini & Epstein, 1999). Therefore, in addition to a tendency to respond automatically when an action is simple and well-practised, there may also be dispositional tendencies to rely more strongly on one or other mode of acting. As a result, people with a preference for experiential thinking may be expected to have a tendency to rely more on their automatic rather than rational system, and therefore to form habits faster.

1.5 Thesis overview

This study aimed to investigate potential predictors of habit formation through a longitudinal study tracking the process of habit formation for dental flossing and taking vitamin C tablets. The study included interventions designed to promote behaviour change in a manner expected to lead to habit formation (Lally & Gardner, 2013). Behaviour was measured over the course of sixteen weeks, along with measures of automaticity and other psychological variables. This enabled investigation of several hypothesised predictors of habit formation. Knowledge of the features which predict gain in automaticity, and how those features are seen to affect both automaticity and behaviour, will assist in the development of habit theory. This will lead to increased knowledge of how to effectively promote automaticity gain, and therefore sustained changes in healthy behaviour.

1.6 Hypotheses

Each hypothesis is listed below, along with a brief summary of the rationale underpinning it. The target behaviour in which each hypothesis is tested is also specified.

H1: Inserting a new behaviour in the middle or end, rather than at the beginning, of a behavioural event, is more likely to lead to habit formation.

Active memory is disrupted across event boundaries, therefore it will be harder to insert a new behaviour at this point in a routine. Event boundaries are also associated with increased brain responding, meaning that actions occuring at this point are less likely to become automatically activated. This will be investigated through the manipulation of whether participants are instructed to floss their teeth before or after brushing.

H2: Interventions based on sexual/social attractiveness (a basic human motivation) will be more effective in promoting behavioural automaticity than interventions focussing on plans to improve health.

Health knowledge is often not a strong predictor of behaviour. In contrast, attraction is a basic human motivation, which may be more effective at promoting behaviour change. Acting in a way that is believed to lead to greater physical attraction may be more rewarding than doing an activity that is good for your health, thus leading both to greater levels of behaviour repetition and greater automaticity. This will be investigated through randomisation of participants to receive interventions for flossing either based on attraction or health.

H3: Reward will moderate the behaviour-automaticity gain relationship, by leading to greater increases in automaticity for each behaviour repetition.

This effect is expected from theories of animal learning, whereby rewarding outcomes strengthen the association between the stimulus and response. This moderation effect has also been observed in studies of existing habits. Using variables measuring reward, this can be investigated for both the behaviours of flossing and taking vitamin C tablets.

H4: Different psychological features will serve as rewards to reinforce behaviour. These are:

a. **Reward as pleasure.**
b. **Reward as positive attitude (both global attitudes, and specific beliefs about outcomes).**
c. **Reward as intrinsic motivation (as opposed to extrinsic motivation).**

It is not clear what aspects of experience may function as reward, therefore different potential rewarding variables will be tested. That pleasurable sensory experiences will be rewarding and lead to habits is expected from the animal learning literature, which often uses rewards with a high hedonic sensory value, such as food. It is known that satisfaction with the outcome is associated with maintenance, and a positive effect of attitude on automaticity has been observed in the past, therefore the effects of positive attitudes about the outcomes of the behaviour will also be tested. These will include both general attitudes about whether the behaviour is beneficial, and about beliefs of specific potential benefits of the behaviour. As the effect of intrinsic motivation on existing habits has been demonstrated, the effect on the formation of a new habit will be investigated here.

These questions will be investigated for the behaviour of taking vitamin C tablets. The different potential reward types will be measured but not manipulated.

H5: Higher prospective memory ability will be associated with greater initiation rates of a new behaviour.

Prospective memory is the ability to act upon delayed intentions, which is necessary for behaviour change attempts. Therefore, prospective memory ability may be expected to be related to the ability to initiate a new behaviour, which may impact upon later habit formation.

This (and the other individual difference variables described below) will be investigated for both behaviours of flossing and taking vitamin C tablets, but the results will be presented in a separate chapter.

H6: Personality traits as measured by the Big 5 will relate to the likelihood of maintaining a new behaviour, and of forming stronger habits.

Some personality traits, such as neuroticism and extraversion have been associated with behaviours which may be thought of as habitual. Conscientiousness has been suggested to confer an advantage to behaviour initiation and repetition. Therefore, the effect of these traits on behaviour repetition and habit formation will be investigated here.

H7: People with a stronger personal need for structure will be more likely to initiate and maintain a new behaviour, which is likely to lead to increased likelihood of forming stronger habits.

People with more highly structured lifestlyes and stable routines may find it easier to add a new behaviour, through regularly encountering the relevant cues. Such people may also be more likely to achieve the context-dependent repetition required for habits to form.

H8: Preference for experiential as opposed to rational thinking style will be associated with the tendency to form stronger habits.

Habit can be considered as relating to the automatic rather than reflective system in dual process models. Rational and experiential thinking styles are thought to relate to these two systems, and therefore, preferrence for experiential rather than rational processing may be expected to be associated with a greater tendency to form habits.

Chapter 2: Methods

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2.1 Overview

The present study tracked the adoption of a new behaviour and subsequent habit formation in a sample from the general population living in and around London. Study involvement lasted sixteen weeks. Participants were given interventions to promote the target behaviours of taking a vitamin C tablet (at the start of their participation) and flossing (four weeks into the study). There was a visit by the reasearcher at weeks zero, four and sixteen. In addition, every four weeks during the course of the study, participants completed an online questionnaire including measures of behaviour, automaticity and motivation. Individual differences measures were taken at the first questionnaire.

In addition to self-report, this study used electronic sensors to monitor target behaviours in order to track patterns of behaviour every day. This technique could also identify the context in which people are performing the behaviour through the monitoring of other activities performed in the same location (the bathroom). However, the processing of the sensor data is still underway, therefore the PhD will look at just the questionnaire data. Due to constraints on the number of sets of sensor equipment that could be purchased, at least two participants were recruited per household. These equipment constraints also meant that the study could not run concurrently for all participants; therefore, the process was repeated over three waves of data collection, so that the required sample size could be acheived.

2.2 Selection of target behaviours

Target behaviours were chosen according to several desirable characteristics. They had to be ideally performed at least once a day, and be able to be associated with a specific place, and point in a routine. Target behaviours should be simple, as complex behaviours (those with more behavioural subcomponents, or requiring a higher degree of cognitive flexibility) are likely to retain significant levels of cognitive processing, making them less likely, (or slower,) to become habitual (Lally & Gardner, 2013; Maddux, 1997; Redish, Jensen, & Johnson, 2008; Ruh et al., 2005). Target behaviours should be ones that are not performed by the majority of the population, to aid recruitment of participants who do not perform these behaviours regularly. In order to be easily monitored by our sensor system, they had to be behaviours which could take place in the bathroom at home, and involve manipulation of an object to which a sensor could be attached.

Two target behaviours were selected, in order to be able to investigate more hypotheses for the limited number of participants that could be included, given the constraints of time, and the number of sets of equipment that could be purchased.

Initially, one of the behaviours chosen was handwashing with soap after defecation. Past research suggests that rates of handwashing with soap are much lower than would be expected or desirable (Drankiewicz & Dundes, 2003; Judah et al., 2009), and that people vastly over report the frequency of their handwashing behaviour (Haas & Larson, 2007; Manun'Ebo et al., 1997). However, once the first of the three waves of participants had been recruited, inspection of baseline automaticity scores for handwashing with soap after defecation revealed that they were already very high, giving little room for improvement. Therefore, this target behaviour was dropped for the subsequent two waves, and taking vitamin C tablets was substituted instead. Throughout the study, the other target behaviour was dental flossing. (The procedure of the study, along with any changes made during the data collection period, is outlined in Table 1.)

Name	Time	Process
T0	0 weeks	**Home visit:** Behaviour monitoring equipment set up **Questionnaire completion:** Online vitamin C intervention Behaviour self-report, automaticity, context stability†, motivation/reward, individual difference items
T1	4 weeks	**Home visit:** Face-to-face flossing intervention **Questionnaire completion:** Behaviour self-report*, automaticity, context stability†, motivation/reward
T2	8 weeks	**Questionnaire completion:** Behaviour self-report*, automaticity, context stability†, motivation/reward
T3	12 weeks	
T4	16 weeks	**Home visit:** Behaviour monitoring equipment removed Semi-structured interview **Questionnaire completion:** Behaviour self-report, automaticity, context stability†, motivation/reward

Table 1 Study procedure
** Behavioural self-report at T1-T3 was only added towards the end of the first wave of participants.*
† The context stability items were only added for the second and third waves of data collection.

2.2.1 Flossing

Flossing is a preventative health behaviour, which removes plaque from areas that brushing cannot reach (Brothwell, Jutai, & Hawkins, 1998), thereby preventing cavities and gum disease (Bader, 1998). Flossing has been shown to be associated with greater plaque reduction than brushing alone (Sjogren, Lundberg, Birkhed, Dudgeon, & Johnson, 2004). Flossing also potentially has more systemic health benefits (Duley, Fitzpatrick, Zornosa, & Barnes, 2012), as gum disease has been associated with pre-term delivery and low birth weight (Offenbacher et al., 2001), and increased risk of cardiovascular disease (Wu et al., 2000). Flossing is most effective when performed daily, preferably in the evening, to prevent bacteria build-up when asleep; (Lindhe, Lang, & Karring, 2009), and typically occurs in an unvarying context (the bathroom). Due to the stability of likely context, and the frequency of desired performance, flossing thus offers an ideal behaviour for purposive habit formation research.

Flossing was also a desirable candidate behaviour as it has been previously studied in work on habit formation (Judah et al., 2012; Orbell & Verplanken, 2010). Implementation intentions (detailed if-then plans specifying the situation in which a behaviour should be performed) have been shown to be effective at promoting habit formation over four weeks (Orbell & Verplanken, 2010). The other study involved an intervention whereby participants were instructed to floss either before or after brushing (Judah et al., 2012). The results of that study suggested that flossing after toothbrushing was more likely to become a habit than flossing before toothbrushing. However the results four weeks following the intervention were only tending towards significance (p=.075), and the significant difference at eight month follow-up was only on the small subsample of participants who responded at this stage (29/50, 58%). Therefore, the present study will test the finding about placement in routine on a larger sample, and for a longer period post-intervention. The exploratory study also revealed that attitudes had a direct impact on habit after four weeks, independent of behaviour (Judah et al., 2012). This informed the hypothesis that additional variables may act as rewards to reinforce habit formation. Though that study did not see a significant interaction between behaviour and attitude on habit at one month, which would be expected if positive attitudes were reinforcing the effect of repetitions on habit formation, a true interaction may have not have been found due to the small sample size. Therefore, the same behaviour was chosen in order to investigate these findings further.

2.2.2 Taking vitamin C tablets

Taking vitamin C tablets was the second behaviour chosen, as it is a simple behaviour that can be performed once daily, and which may typically occur in a fixed location, and so is a good candidate for habit formation. Work testing the effects of implementation intentions has shown that they lead to higher levels of vitamin C tablet taking over the course of three weeks (Sheeran & Orbell, 1999). Therefore, implementation intentions are likely to be an effective way to promote behaviour adoption, hopefully leading to habit formation across our sample.

Adequate vitamin C intake is an important health behaviour. Vitamin C is an antioxidant, which can protect cells from the harmful effects of free radicals. It is important in helping the body absorb iron, and for bones, connective tissue and skin. Despite the well-known health benefits of vitamin C, a considerable proportion of the population may still be deficient, suggesting that supplementation may be necessary for some people. In a low-income sample in the UK, 25% of men and 16% women were found to be vitamin C deficient, and a further 20% had depleted levels (Mosdol, Erens, & Brunner, 2008). In a large scale survey in America in 2003-2004, 13% of the population were found to have deficient levels of vitamin C (Schleicher, Carroll, Ford, & Lacher, 2009).

There is evidence that taking vitamin C supplements may result in people having milder symptoms when they get a cold, or slightly shorter colds (Douglas & Hemila, 2005; Hemila, 2007). It has been claimed that taking vitamin C supplements leads to a variety of potential health benefits, such as decreasing the risk of cancer and heart disease (Hercberg et al., 2004; Qiao et al., 2009). However many of these claims have been disputed (Cook et al., 2007; Sesso et al., 2008; Shekelle et al., 2003). This study was not aiming to advocate for the benefits of a specific behaviour, but to look into determinants of habit formation. This behaviour may also provide insights into how to form habits to promote medication adherence, as the behaviours are similar. Participants were told at the end of the study that though supplements may be helpful for those not getting adequate vitamin C in their diet, in general it is more beneficial to health to get vitamin C intake from dietary sources.

2.3 Behaviour monitoring sensor system

Self report has been shown to be biased (Manun'Ebo et al., 1997; Scott, Schmidt, Aunger, Garbrah-Aidoo, & Animashaun, 2008), and can be associated with a high rate of missing data

(Lally et al., 2010). Self-monitoring is also an effective way of changing behaviour (Dombrowski et al., 2010; Michie et al., 2009; Suresh, Jones, Timothy, & Asimakopoulou, 2012), and so, measuring behaviour using self report is also a behaviour change technique. Hence, we used electronic sensors to monitor behaviour to reduce the need for self-report. The sensors were a commercially available system from Elpas Solutions, which were tested for their novel use in this application (Judah, De Witt Huberts, Drassal, & Aunger, in prep). The system had the advantage of being able to differentiate between participants, and non-participating occupants or guests to the household, and to identify which participant is performing the behaviour.

The system consisted of waterproof sensors, which participants were instructed to wear on their wrist for the duration of the study, and sensors which were also affixed to various objects in the bathroom (toilet flush, toilet roll holder, toothbrush cup, toothpaste, floss, tap, soap dispenser, vitamin C bottle). The sensors were slightly smaller than a box of floss, so could be affixed to the objects associated with the target behaviours, i.e. the floss box, and the bottle of vitamin C tablets. These sensors recorded whether they are in motion, and also if they are in range of other sensors called exciters. The exciters were placed under the sink and on the toilet cistern, and were set to define a zone (of sensor detection) with a radius of 15cm. The wireless signals from the sensors were received by another device called an RF Reader, which was connected to a plug computer called a Dreamplug supplied by GlobalScale Technologies. The computer timestamps the incoming data, stores and compresses it, and transmits it to a server on the LSHTM system. This enabled remote monitoring of the equipment and sent daily notifications to alert the researchers of any problems. As the system monitored various objects in the bathroom, this data would include a rich description of the wider routines in which the target behaviours occurred, thus allowing measures of routine or context stability to be objectively measured.

The dataset collected was very rich, but also complex. A software program was developed to identify from the stream of sensor data which behaviours were being performed by which individual. The development of this program took significantly longer than anticipated, and furthermore, is time consuming to use. Therefore, the data processing is still underway, and it was decided that the thesis would include only the monthly self-report data. This was possible because shortly after the start of the study, observed equipment failures led to the introduction of behaviour self-report questions within the monthly questionnaires so that there would be some record of the behaviour even if there were problems with the sensors.

2.4 Interventions

2.4.1 Flossing intervention: The routine Placement and motivation Focus study

The intervention for flossing was designed to test the following hypotheses:

H1: Inserting a new behaviour in the middle or end, rather than at the beginning of a behavioural chunk is more likely to lead to habit formation.

H2. Interventions based on attractiveness (a basic human motivation) will be more effective in promoting behavioural automaticity than interventions focussing on plans to improve health.

The flossing intervention took place at T1 (four weeks after the start of the study, when the monitoring equipment was set up), and was delivered by the reasercher, individually to each participant, as a face-to-face intervention. The intervention was delivered in the home of the participant, and lasted approximately 30-40 minutes. First the participants' evening scripts were recorded (as described below). In order to test the hypotheses, participants were randomised by household into two different conditions, in a two by two design. Participants were randomised to be instructed to floss before or after toothbrushing (Before TB and After TB groups), in order to test the hypothesis about the effects of adding a new behaviour to the beginning or middle/end of an event (Placement). Participants were also randomised to receive an intervention encouraging flossing based on the benefits of flossing to dental health or the benefits to attractiveness (Focus), which will be refered to as the Health and Attraction groups.

The format of the habit formation intervention was the same across all conditions, and consisted of a leaflet given to participants, which was also explained orally by the researcher. The common intervention features for the different groups included stating positive consequences of flossing, and instructions on how to perform the behaviour, including how and when to floss (Michie et al., 2011). Action planning was utilsed both to assist behaviour initation, and to guide context-dependent repetition, through guidance in the formation of implementation intentions specifying when and where participants will floss (Gollwitzer, 1993). These were based on the scripts that were recorded for each participant, and whether they have been assigned to perform the target behaviours at the beginning or middle/end of a behavioural event. Furthermore, a behavioural contract was undertaken to support the initiation attempt: participants wrote down their implementation intention on the leaflet, and

read this aloud along with a pledge: "I pledge to floss my teeth every night before/after brushing".[1] They were instructed to read this out three times until they could repeat it without looking at it, in order to commit the implementation intention and the pledge to memory.

The intervention condition of the placement of flossing before or after brushing was manipulated in the leaflet, by giving the benefits of flossing at each of these points according to the condition the household was assigned to (a plausible rationale for both can be found).

The Attraction versus Health condition was manipulated using information in the leaflet, both presented as facts, and a testimonial about a person's reported experience of the consequence of flossing. The leaflets were matched as closely as possible across the different conditions, in terms of the intensity, the timeframe of the benefits, and the area of the leaflet used for pictures. The Health condition leaflet contained information on health consequences of flossing, including statements about how flossing prevents cavities and gum disease, and about evidence suggesting a connection between gum disease and heart disease. The pictures in the Health leaflet were of dentists and teeth. The Attraction condition leaflet contained information about the social and emotional consequences of flossing. There were statements about how flossing makes your teeth look brighter and whiter, prevents bad breath, and that people with whiter teeth are rated as looking younger. The pictures in the Attraction leaflet were of people with attractive smiles, and smiling couples. The intervention leafelts are shown in Appendix 1. Following the presentation of the leaflet, any questions of the participant were addressed.

The extent to which participants experience the intended motivations to perform the behaviours and perceived rewards reinforcing them were verified using motivation items in a questionnaire, which was completed at baseline, at this session, and every four weeks throughout the study. This can test whether the intervention conditions had the desired effects on beliefs about attraction and health.

[1] Participants were asked to try to floss their teeth in the evening and to create an implementation intention related to this point. However, participants who expressed that this would be difficult given their routine were encouraged to try to floss in the morning instead.

2.4.2 Vitamin intervention: The reward study

The effect of rewards on vitamin C behaviour and automaticity was measured using a correlational design. All participants received the same intervention, and the different types of experienced reward were measured. The hypotheses tested here were:

H3: Does reward moderate the behaviour-automaticity gain relationship, by leading to greater increases in automaticity for each behaviour repetition?

H4: Different psychological features will serve as rewards to reinforce behaviour. These are:

a. Reward as pleasure (positive sensory experience).

b. Reward as positive attitude (both global attitudes, and specific beliefs about outcomes).

c. Reward as intrinsic motivation (as opposed to extrinsic motivation).

The vitamin intervention was delivered at T0 (the first session). This was because in another study of vitamins, when participants were first told that it was up to them whether or not they take them, and only later instructed to take them, the rates were almost at ceiling during the supposed baseline period (Sheeran & Orbell, 1999). This implies that the mere act of giving someone vitamin tablets is likely to lead to potentially high rates of usage. Therefore it was decided that the vitamin intervention should take place at the start of the study. The intervention was delivered online, as part of the questionnaire that participants were requested to complete. Participants were presented with some information about health consequences, regarding the function of vitamin C in the body, and of some possible benefits of taking vitamin C supplements. To encourage people to engage further with these statements, the benefits were reframed as questions, and participants were asked to indicate on an five point scale how likely it was that they would be able to achieve these benefits through taking vitamin C tablets (1=I can definitely not achieve this if I took vitamin C, 5=I can definitely achieve this if I took vitamin C). These were the vitamin belief items, and which measures the salience of the consequences to the participants. Action planning was used by instructing participants to think about precisely when in their routines they would take vitamin C, and write this down (Sheeran & Orbell, 1999). The intervention is shown in Appendix 2. Some restructuring of the physical environment took place, both in the setting up of the sensors which occurred at the same time as this intervention, the provision of vitamin C

tablets, and also, the participants were asked to consider whether leaving a cup in the bathroom near the vitamin C tablets would assist in performance of the behaviour.

In the questionnaire at T1 (four weeks after the initial vitamin C intervention), there was some further material to boost the intervention, in case levels of uptake had fallen already (Fleig, Pomp, Schwarzer, & Lippke, 2013). Within the online questionnaire, participants were asked three multiple choice questions about the benefits of vitamin C, and then given the answers, along with some explanation, in order to reiterate health benefits. In order to support coping planning, they were asked questions about any barriers they might have encountered along the way. These included asking when they take their vitamin C tablet, whether this was a good time for them to take it, and to write down if they want to try taking it at a more convenient time. They were also asked that if they forget to take it because they cannot see it, whether they want to move it to a more visible place. This would be restructuring the physical environment to enhance the reminding effect of the focal object.

2.5 Self-report measures

A variety of self-report measures were collected via online questionnaires, which were completed every four weeks during the study.

2.5.1 Habit measurement

Selection of a habit measure

Various measures have been developed for habit strength. A widely accepted measure is the Self Report Habit Index (SRHI) (Verplanken & Orbell, 2003), a 12 item scale which has been used across a variety of behaviours (de Bruijn, Kremers, Singh, van den Putte, & van Mechelen, 2009; de Bruijn & van den Putte, 2009; Gardner et al., 2011; Lally et al., 2010). The SRHI also demonstrates results consistent with the theoretical predictions that habit should correlate strongly with behaviour, and moderate the relationship between intention and behaviour when the context is stable (Gardner et al., 2011). However, it has been criticised, because the main component of habit is held to be automaticity (Gardner, 2012), yet the measure also includes items measuring identity, as well as frequency. Identity has been observed to not correlate well with habitual behaviours (Wood et al., 2002). Frequency cannot distinguish

between behaviour that is habitual or reasoned (Ajzen, 2002; Verplanken & Wood, 2006). Frequency is also both a precursor of and a consequence of automaticity (Sniehotta & Presseau, 2012), but is not an 'active ingredient' of habit (Ajzen, 2002; Sniehotta & Presseau, 2012). Furthermore, automaticity is the only component of habitual action which distinguishes it from repeated deliberative action, and is the key component when researching formation of new habits. Therefore, a revised measure uses four of the SRHI items related to automaticity to compose a scale called the Self Report Behavioural Automaticity Index (SRBAI) (Gardner, Abraham, Lally, & de Bruijn, 2012b). This index has been shown to moderate the intention behaviour relationship as well as the SRHI, while being clearer conceptually. The four items of the SRBAI were selected out of the seven SRHI automaticity items, as they were found to be most strongly and consistently rated to be measuring automaticity.

There are however criticisms of self-report measures of habit, due to the claim that it is not possible to consciously remember doing something that occurs without awareness (Sniehotta & Presseau, 2012). However, the SRBAI does not include reference of not being aware of performing the behaviour, so the behaviour may be initiated automatically, but not necessarily occur without conscious awareness. An alternative method of measuring habits is using reaction time measures (Danner et al., 2008; Keatley, Clarke, & Hagger, 2013; Nosek, Greenwald, & Banaji, 2007). However, these are difficult to administer, and it is not clear whether the cue selected as a prime is applicable to all participants. There is also evidence that experiencing a subjective urge to respond correlates strongly with actual habitual responses in a lab based task (Gillan et al., 2014), suggesting that self-report measures of habit may be sufficient.

The scale selected for this study was therefore the SRBAI (Gardner, Abraham, et al., 2012b). The measure involves completing the stem: 'Behaviour X is something…': 'I do automatically', 'I do without thinking', 'I do without having to consciously remember', 'I start doing before I realise I'm doing it' using a seven point Likert scale (1=Strongly disagree, 7=Strongly agree).

SRBAI specification

In this study, the stems were 'Flossing my teeth in the morning/evening' and 'Taking a vitamin C tablet every day'. While the flossing stems were not specifically related to the actual placement of the flossing behaviour (i.e. before or after toothbrushing) this enabled better comparison between the scores from different participants. Participants were asked to try to

floss their teeth in the evening, which is why the time of day was specified in the flossing questions. Some participants decided that they wanted to try to floss in the morning, but as the SRBAI was asked separately for both timepoints, this meant that the main outcome could be set as flossing automaticity specified as the target timepoint by the participant at the time of the intervention. No specific time or situation was specified in the stem measuring vitamin automaticity, as participants could choose to do this at any point in the day, and so it would be harder to identify an appropriate context in the stem.

There was also an option in the SRBAI specified as "N/A, I never floss my teeth in the morning/evening" or "N/A, I never take vitamin C tablets". This option was included to avoid the tendency for participants who never perform the behaviour to give the mid-point response of "neither agree nor disagree" (Gardner & Tang, 2014). This inclusion means that the question encompasses both a binary outcome (whether someone responds that they ever perform the target behaviour or not), and - for participants who report ever performing the behaviour - a continuous outcome of how strongly automatic the behaviour is rated to be according to a Likert scale. Responses were therefore separated later into these two scores: one binary score of whether someone states that they ever do the behaviour or not, and a continuous score of the strength of their habits. The "N/A" options was assigned an automaticity score of zero, apart from when there was a possibility that participants may have implicit habits (Gardner, 2014), when the score was treated as missing. Implicit habits were deemed to be possible for participants who might have done the target behaviour regularly before, which was assessed from the baseline questionnaires.

For the behaviour of flossing, participants were asked at baseline if they had flossed regaulrly before. Therefore, participants who responded that they had flossed their teeth regularly before were treated as having a missing automaticity score if they gave the "N/A, I never floss..." response for the SRBAI at baseline or T1 questionnaires. Participants who had never flossed regularly before were treated as having an automaticity score of zero, as they have not performed the behaviour in a way conducive to habit formation, so there is not the possibility of having implicit or dormant habits.

For the behaviour of taking vitamin C tablets, the only question about baseline behaviour was "how often do you currently take a vitamin C tablet per month on average?". As it cannot be known whether or not someone has performed the behaviour regularly before from this question, everyone who gave an "N/A" score to the SRBAI at baseline had their automaticity treated as missing.

Following the intervention timepoint (T0 for vitamin C, and T1 for flossing), participants were assumed to have had been reintroduced to the target behaviours, so were given a zero score regardless of whether they may have had an implicit habit at the start of the study. The overall scores were calculated as the mean of the four SRBAI items, so could range from zero to seven. Cronbach's alpha for both the flossing SRBAI (in the evening), and the vitamin SRBAI was 0.98.

2.5.2 Context stability

In order to get a measure of context stability, questions were asked about whether participants perform the target behaviours of flossing and taking vitamin C "in the same place every time" and "at the same point in my routine every time" using a seven point Likert scale (1=Strongly agree, 7=Strongly disagree) (Norman & Cooper, 2011). While this question has been asked before for 'the same time every time', as the exact timing of the performance of the target behaviour may vary, for example, depending on what time the person gets ready for bed on any particular evening, the point in the routine was deemed to be a more appropriate contexual measure (Kvavilashvili et al., 1996). As in the SRBAI, an option for "N/A, I never floss/take vitamin C tablets" was included to reduce the chance of mid-point responding. This was treated in the same way, in that participants at the intervention point or earlier who may have performed the behaviour regularly before[2] (and so may have latent habits), had their scores excluded at that instance, or treated as a zero otherwise. The overall score was calculated as the mean of the two scores, so could range from zero to seven. Cronbach's alpha for both the flossing and vitamin C context stability questions was 0.94.

2.5.3 Script recording

To establish how the target behaviours of flossing can be incorporated into the idiosyncratic routine of each participant, and to assist in implementation intention development, their evening script was elicited (Judah et al., 2012). Participants were asked to list what they do on a typical evening from when they start getting ready for bed until they get into bed. Each listed activity was written on a separate Post-it note. Participants were then asked to group

[2] I.e. participants who responded at baseline that they had flossed their teeth regularly before, and all participants who gave the "N/A" context stability response for vitamin C tablets, as there was not an equivalent question about past regular performance of the behaviour.

together activities that they feel belong together conceptually in order to cluster the activities according to the script hierarchy. Participants were asked to break down the activities listed in the cluster containing toothbrushing, on the level of "picking up your toothbrush and putting on the toothpaste". These were listed on new Post-it notes. Participants were asked whether the order of these events were fixed or flexible, and if so, in what way. The scripts were referred to when participants formed their implementation intentions, so a specific and personalised "prior action" cue (Lally et al., 2010; McDaniel & Einstein, 2007; Orbell & Verplanken, 2010) could be selected.

2.5.4 Motivation

Due to the different hypotheses being tested, different measures of motivation were employed for flossing and taking vitamin C. The flossing items combined two different types of motivation questions. The first type was based on Azjen's Theory of Planned Behaviour (Ajzen, 1991, 2006) with at least two items for each of intention, attitude, subjective norm, and perceived behavioural control. The second part was based on different specific motivations, to test the impact of the different Focus interventions of attraction and health belief (Aunger & Curtis, 2013; Aunger et al., 2010; Curtis, Danquah, & Aunger, 2009; Judah et al., 2009), as well as questions to measure whether the behaviour was experienced to be rewarding or punishing. An item was asked at the final questionnaire (T4) about the perceived relative effectiveness of flossing over brushing. The scale was pre-tested to ensure internal validity for each construct. The final items and Cronbach's alpha for the flossing motivation scores are shown in Table 2.

The vitamin C measures were constructed to test different conceptions of reward, or features which may be experienced as more or less rewarding. This included four different conceptions of reward: 1. reward as pleasure (i.e. physical reward) 2. reward as general attitude about the behaviour, 3. specific beliefs of the benefits of the behaviour, and 4. intrinsic motivation. Items assessing general reward or satisfaction were also measured.

The relative autonomy questions were constructed with reference to to the BREQ-2 (Markland & Tobin, 2004). This included items measuring amotivaton, external regulation, introjection, identification, integration[3] and intrinsic motivation[4]. The TPB constructs of intention and

[3] Integration items are not included in the BREQ-2 due to difficulty distinguishing it from identified or intrinsic, and so these items were adapted from those used in other studies (Pelletier, Tuson, Green-Demers, Noels, & Beaton, 1998; Wilson, Rodgers, Loitz, & Scime, 2006).

perceived behavioural control were also measured. At T0, T1 and T4, the six questions about belief of the benefits of taking vitamin C tablets were asked. The items and Cronbach's alpha scores for each construct are shown in Table 3 below.

All items were measured on a seven point Likert scale (1=Strongly disagree, 7=Strongly agree), unless indicated otherwise. The mean of the items was calculated for the overall item score. For flossing the target behaviour was stated as "…to floss my teeth every evening", and for vitamin C is was "…to take a vitamin C tablet every morning".

2.5.5 Behaviour self-report

As part of each questionnaire, participants were asked to self-report the frequency of performing the target behaviours for the previous week. This was to validate the sensor measures, and also to provide some data as back-up in case of sensor failure. For flossing, participants were asked the number of times they flossed in the morning, and in the evening, in the past week. The score was used for the time of day that participants undertook to floss at the time of the intervention, resulting in a 'target time' flossing frequency, and a 'non-target time' flossing frequency. For vitamin C, participants were simply asked the number of times they had taken their vitamin C tablet in the past week.

At baseline (T0), participants were instead asked the number of times they do each of the target behaviours a month on average. When this was compared graphically to the responses from the later questionnaires of self-report of behaviour in the previous week, the monthly scores were divided by four. For flossing, participants were also asked if they had ever flossed their teeth regularly before.

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[4] Amotivation represents a lack of any intention to engage in a behaviour and is a completely non-self-determined form of regulation. External regulation involves engaging in a behaviour only to meet external pressures or for external rewards. Introjected motivation involves the internalization of external pressures, in order to avoid guilt or to maintain self-esteem. Identification represents a conscious acceptance of the behaviour as being important in order to achieve personally valued outcomes. Integrated motivation concerns the assimilation of identified regulation so that performing the behaviour is fully consistent with one's sense of self. Intrinsic motivation involves performing an activity for the enjoyment and satisfaction inherent in engaging in the behaviour itself (Markland & Tobin, 2004).

Construct	Items	Cronbach's alpha
Intention	I aim to... I intend to...	0.92
Perceived Behavioural Control (PBC)	It is completely up to me whether I... I have complete control over whether I...	0.74
Descriptive Norm	I think most people who are important to me... I think the people in my life whose opinions I value...	0.83
Subjective Norm	I think people who are important to me expect me to... The people in my life whose opinions I value would approve of my...	0.66
Experiential Attitude	I think flossing every evening is: Very enjoyable-very unenjoyable Very pleasurable-very unpleasurable	0.81
Instrumental Attitude	I think flossing every evening is: Very beneficial-very harmful Very useful-very useless	0.63
Attractiveness Motivation	...makes me more attractive ...makes my teeth look nicer ...makes my breath smell better	0.83
Health Belief	...reduces plaque ...is painful to do ...will prevent gum disease ...will prevent dental problems	0.87
Health Outcome Evaluation	Having good dental health is important	-
Attractiveness Outcome Evaluation	Having teeth which look nice is important	-
Hassle	...is time consuming ...is laborious	0.73
Reward	...is satisfying I like... ...feels pleasant to do	0.89
Punishment	...is uncomfortable …is painful to do	0.79
Perceived relative effectiveness (T4 only)	Do you believe that flossing your teeth has a positive impact over and above that of toothbrushing? (1=Definitely not, 5=Definitely)	

Table 2 Motivation questions for flossing
All items were measured on a seven point Likert scale (1=Strongly disagree, 7=Strongly agree), unless indicated otherwise. The mean of the items was calculated for the overall item score. The target behaviour was stated as "…to floss my teeth every evening".

Construct	Items	Cronbach's alpha
Intention	I intend to... I aim to...	0.91
PBC	It is completely up to me whether I... I have complete control over whether I...	0.82
General reward	Taking a vitamin C tablet is: Rewarding-unrewarding Satisfying-unsatsfying	0.79
Pleasure	Taking a vitamin C tablet is: Pleasant-unpleasant Something I like a lot-something I dislike a lot	0.82
Global attitude	Taking a vitamin C tablet every day is: Very beneficial-very harmful Very useful-very useless	0.85
Vitamin belief (measured at T0, T1 and T4 only)	To what extent do you believe that if you took vitamin C tablets, you would achieve the following benefits: - reduction in the length and severity of colds - reduction in effects of aging on skin - protection against cancer and cardiovascular disease - protection against damage caused by exercise - protection of the immune system against stress - protection against the effects of carbon monoxide on vitamin levels	0.91
Relative autonomy subscales		
Amotivation	I don't see any reason to... I don't see why I should bother... ...is a waste of time	0.90
External regulation	I would take vitamin C because it is expected of me I would take vitamin C tablets because other people think I should	0.73
Introjection	I would feel like I have failed if I don't... I would feel guilty if I didn't...	0.84
Indentification	...is good for my health ...is important to me I value the benefits of...	0.81
Integration	...is consistent with my values ...is an integral part of my life ...is part of the way I have chosen to live my life	0.83
Intrinsic motivation	...is something I like doing ...gives me pleasure and satisfaction ...is something I enjoy	0.93

Table 3 Motivation/reward questions for taking a vitamin C tablet
All items were measured on a seven point Likert scale (1=Strongly disagree, 7=Strongly agree), unless indicated otherwise. The mean of the items was calculated for the overall item score. The target behaviour was "…to take a vitamin C tablet every morning".
Note: for the baseline questionnaire when people do not necessarily have experience of taking vitamins, the questions were reworded in the form: if I were to take vitamins during the study period, it would be because...

2.5.6 Individual difference measures

These were measured at the baseline (T0) questionnaire only. The full scales for all questionnaires are shown in Appendix 3 –Appendix 6.

Prospective and Retrospective Memory Questionnaire

In order to see whether poor prospective memory hinders behaviour initiation, prospective memory was measured. The Prospective and Retrospective Memory Questionnaire (Smith, Del Sala, Logie, & Maylor, 2000) has eight items for each type of memory, such as "Do you decide to do something in a few minutes time and then forget to do it?" (prospective memory) and "Do you fail to recognise a place you have been to before?" (retrospective memory), which were rated on a five point scale of how often participants experience each item (1=never, 5=very often). A high score denotes poor memory. The full scale is shown in Appendix 3. The mean for each type of memory was calculated, giving an overall score between one and five. Cronbach's alpha for prospective memory was 0.90, and for retrospective memory was 0.82.

Personal Need for Structure

It may be expected that people who prefer a more structured lifestyle or who have more regular routines may find it easier to initiate a new behaviour, or form habits more easily. One way to measure this is using the Personal Need for Structure (Neuberg & Newsom, 1993). This comprises twelve items, such as 'I'm not bothereed by things that interrupt my daily routine', 'I don't like situations that are uncertain', 'I find that a consistent routine enables me to enjoy life more'. The scale includes four reverse scored items. Responses are given on a seven point Likert scale (1=strongly disagree, 7=strongly agree). The full scale is shown in Appendix 4. The overall score is calculated as the mean of the twelve items, giving a score between one and seven. High scores indicate a higher need for structure. Cronbach's alpha for personal need for structure was 0.86.

Rational and Experiential Inventory

There is some evidence that preference and ability for experiential thinking style (associative, rapid and unconscious) is associated with having stronger habits than a rational thinking style (logical, slow and conscious) (Sladek et al., 2008). The two thinking styles can be seen to relate to the automatic and reflective systems respectively. The effect of these preferences on habit formation was tested here using the Rational and Experiential Inventory (Pacini & Epstein, 1999). This is made up of 40 statements, 10 each on rational ability (e.g. "I have a logical mind"), rational engagement (e.g. "I'm not that good at figuring out complicated problems"), experiential ability (e.g. "I trust my initial feelings about people") and experiential engagement ("I generally don't depend on my feelings to help me make decisions"). There are 19 reverse scored items. Responses are given on a five point Likert scale (1=definitely not true of myself, 5=definitely true of myself), and for each of the four subscales, an overall score is calculated as the mean of the ten items, giving a score between one and five. All items are shown in Appendix 5. High scores represent preference for that style. Cronbach's alpha for: experiential ability was 0.77, experiential engagement was 0.71, rational ability was 0.79; rational engagement was 0.84.

Personality

A validated, abridged version of the Big Five provided a measure of personality type (Gosling, Rentfrow, & Swann, 2003). The measure consisted of 10 items, two for each construct (openness to experience, extraversion, optimism, neuroticism, concientiousness) including one reverse scored item for each. The items are presented in the form of pairs of words, and participants must indicate how much they feel the pair of traits apply to them. The items are shown in Appendix 6. Responses are given on a seven point Likert scale (1=strongly disagree, 7=strongly agree). The mean score for each construct was calculated after adjusting the reverse scored items, giving a score for each construct between one and seven. Cronbach's alpha for: extraversion was 0.46, agreeableness was 0.41, concientiousness was 0.49, emotional stability was 0.64, and openness to experience was 0.18. These values are comparable to those from the original paper (Gosling 2003) as there are only two items per construct, which were not designed with high content overlap, though they do have high test-retest reliability. Openness to experience had a much lower alpha than that shown in the original paper, so was not included in the analysis.

2.6 Power calculation

As hypotheses 3-8 will be tested using longitudinal regression and structural equation modelling with an unknown number of covariates (due to the fact that the study is partially exploratory), it was not possible to conduct a power calcuation for these investigations. Therefore, the study was powered on the simple comparisons between the different flossing intervention groups for hypotheses 1 and 2. From the previous work showing an advantage to flossing after brushing compared to before brushing (Judah et al., 2012), an effect size of 0.45 was observed after four weeks, and an effect size of 0.54 after eight months. Given the sample size of 60 participants per group (120 in total), that could be collected due to limits of time and funding, this would give 80% power to detect an effect size of 0.52. This is a medium effect in line with the finding of differences in automaticity between the two flossing placement conditions, several months following an intervention in the previous study. This means there is also 80% power to detect a difference of medium effect size between the Attraction and Health groups. The investigation of the remaining hypotheses was conducted in a more exploratory way.

2.7 Participants

122 participants were enrolled on the study, however four dropped out before the flossing intervention session at T1. These four participants were excluded from all analysis. The study sample therefore consisted of 118 participants, in 56 households, which were split across the three waves of data collection. Participants were told that the study was investigating everyday activites, and testing the effectiveness of the electronic behaviour monitoring equipment for potential use for an elderly population. The information and consent forms are shown in Appendix 7. (Of the 118 participants, a further four did not complete the study, but all data that was collected for these participants was retained in the analysis.)

The characteristics of the sample are summarised in Table 4. Participants had a mean age of 35.7 (SD=11.8), comprising 53 men and 65 women, and were drawn from the general population living in and around London. Recruitment was first carried out using standard channels for recruiting research participants (e.g. participant pools, adverts on social media [e.g. GumTree, Facebook], and emailing science departments in London and asking them to publicise the study). This was time-consuming, and largely ineffective, so we decided to use a professional recruiter for market research to find participants. Thirty five households were

recruited in this way. Participants were each paid £100 for their participation. Participants had to be at least 18 years old. As shown in Table 4, there was a fairly large range of types of occupation and household composition (couples, families etc). The most common occupation types were higher managerial, administrative and professional, and intermediate. Only a small proportion of the sample were students. Nearly half the participants were families with children. The households in the study showed very great variation in standards of living, and properties varied greatly in terms of size and condition. The study was therefore more representative of the general population than typical studies relying on a sample of undergraduate students.

At the point of recruitment, participants were asked how often they floss and take vitamin C tablets, and whether they would be willing to try to do these behaviours regularly. In order to be eligible for the study, participants could floss no more than twelve time a month on average at baseline, and report taking a vitamin C tablet sometimes, rarely or never. This was to ensure that participants did not initally perform the target behaviours regularly, in order for changes in behaviour and habit strengthening to be possible. They also had to be either definitely, probably, or maybe willing to try to do each of the target behaviours, so that there was some level of willingness to engage in the target behaviours. At baseline, participants flossed 3.38 times per month on average (SD=4.04) and took vitamin C tablets 1.53 times per month (SD=3.43). Thirty participants (31%) reported flossing zero times per month on average at baseline. The remaining 81 participants who reported non-zero monthly baseline frequency, reported flossing a mean of 4.87 times a month (SD=4.03). Fifty seven participants (72%) reported taking a vitamin C tablet zero times per month on average at baseline. The remaining 23 participants who reported non-zero monthly baseline frequency, took vitamin C a mean of 4.86 times a month (SD=3.39).

Characteristic		Participants
Age	Mean	35.7 years
	SD	11.8
Sex	Male	53 (44.9%)
	Female	65 (55.1%)
Recruitment source	Market research recruiter	76 (35 households)
	Other*	42 (21 households)
Occupation category†	Higher managerial, administrative and professional	23 (30.2%)
	Intermediate	26 (34.2%)
	Routine and manual	11 (14.5%)
	Student	10 (13.2%)
	Retired	5 (6.6%)
	Unemployed	1 (1.3%)
Household setting	Couple	33 (28.0%)
	Family - with children	56 (47.5%)
	Family - all adults	19 (16.1%)
	Friends	10 (8.5%)
Mean baseline behaviour	Flossing per month	3.38 (SD=4.04)
	Vitamin C per month	1.53 (SD=3.43)

Table 4 Sample characteristics
** Other recruitment sources included various participant pools, social media, London Science departments, and word of mouth.*
† Occupation data was only available from participants recruited from the market research recruiter.

2.8 Procedure

A summary of the procedure can be found in Table 1 above.

2.8.1 T0 (0 weeks): Home visit and questionnaire completion

Following informed consent from the study participants, the Elpas behaviour monitoring equipment was installed in their households. Sensor detection zones were created around the sink and toilet, and the sensors were affixed to the following objects: toilet roll, toilet flush, toothpaste, toothbrush cup, floss, soap, taps and vitamin C bottle. The two (or more) participants per household were also given wristband sensors to wear. They were instructed to wear this sensor throughout the duration of the study (even when asleep and in the shower), to minimise the possibility that they would not be wearing the sensor at any point during the study. While the equipment set-up was taking place, participants were asked to complete the online questionnaire, including the individual differences items, which they accessed using a

personalised link previously emailed to them. This questionnaire included the vitamin intervention, as described above.

2.8.2 T1 (4 weeks): Home visit and questionnaire completion

Participants were visited again, and the flossing interventions were delivered individually according to the description above. Participants were randomised to intervention groups at the start of the study. Following the intervention they were sent the online questionnaire including measures of self-reported behaviour frequency, automaticity, context stability, motivation, and the vitamin booster intervention.

2.8.3 T2 and T3 (8 weeks and 12 weeks): Questionnaire completion

Target behaviours were monitored over the course of the study using the sensors. Participants were emailed at 8 weeks and 12 weeks (T2 and T3) with a link to the questionnaire, which contained measures of self-reported behaviour, automaticity, context stability, and motivation. If participants did not complete the questionnaire within two days, they were sent daily email reminders until the questionnaire was completed (60% of participants required at least one reminder over the course of the study). The mean number of days from receipt of questionnaire to completion was calculated: mean=2.0, SD=3.2 (excluding the questionnaire at T4, which had to be completed prior to the semi-structured interview). Two participants did not complete one of their questionnaires even following reminders, and therefore these variables were treated as missing.

2.8.4 T4 (16 weeks): Home visit and questionnaire completion

Sixteen weeks after the start of the study, participants were visited again. The monitoring equipment was removed, during which time participants were asked to complete questionnaires as before. This questionnaire also included questions about their experience of the monitoring equipment. Participants were asked in a short semi-structured interview about their experience of taking part in the study in terms of the monitoring equipment, about what reminded them to perform the target behaviour, and any barriers to behaviour performance. At the end of this session, participants were paid for their participation.

Following completion of the study, participants were emailed with full debrief information about the purposes of the study. They were told that if they want to discuss this further, or if they had any questions, the researcher would be happy to call them.

The study received ethical approval from the LSHTM Ethics Committee, with application number 5922.

2.8.5 Changes to measurement procedures during data collection

In the second of the three waves of data collection, the questions were introduced on context stability, therefore there is no data for this question from the participants in the first wave. Furthermore, initially the study did not include self-report measures of behaviour, as behaviour was being monitored using electronic sensors. However, due to concerns about equipment failure, the self-report measures of behaviour were introduced into the questionnaires completed every four weeks, towards the end of the first wave of data collection. As described above, in the first wave of participants, the interventions were for flossing and handwashing with soap. However, as the handwashing habits were observed to be at ceiling from T0, this was replaced with an intervention for vitamin C tablets for the second and third waves of participants.

2.9 Analysis

2.9.1 Overview

Hypotheses 1 and 2 - about which of the Placement and Focus interventions work best to increase flossing behaviour and automaticity – were tested using longitudinal regression analysis. This involved fitting mixed effects regression models that allow control of correlations among measures taken on the same individual over time, and on individuals in the same household (Rabe-Hesketh & Skrondal, 2008). Explanatory variables (measured at baseline) for these variations between individuals and households were included (fixed part of the model), with the variables of time (linear, quadratic and cubic), participant and household comprising the random part of the model. Backwards elimination was used to remove non-significant predictors once the random part of the model was specified. This longitudinal regression analysis procedure was also emplyed for the main outcomes in the behaviour of

taking vitamin C tablets, in order to identify baseline predictors of the outcomes, and to enable visualisation of the changes in behaviour and automaticity over the course of the study.

Questions of the effects of rewards and motivations later in the study could not be addressed in this way, as the motivations may change over time (Loehr, Baldwin, Rosenfield, & Smits, 2013), and this change may be affected by the randomisation condition (so the impact of variables cannot be assessed independent of the condition), or by earlier measurements of the outcome (behaviour or automaticity). Therefore only covariates measured at baseline can be included in the regressions described above (Pearl, 2000). The analysis of the dynamic effects of motivations on the habit formation process was conducted using Structural Equation Modelling (SEM) (Ullman & Bentler, 2003). This allowed causal claims to be made about the relationships between the variables, as well as allowing consideration of explanatory variables measured following the intervention. For the vitamin analysis, the different potential reward types suggested will be tested using the SEM models. For the more exploratory flossing analysis, in order to refine the number of variables to be tested at this stage, the motivation variables were screened to see which may be potential predictors of automaticity. The criteria set for this were that their baseline measurements must either predict later automaticity (which is all that could be tested using the mixed effects regression models for automaticity), or the variable must vary over time (as if it does not vary over time, and if the score at baseline does not predict automaticity, then the later score cannot either). The first criterion was tested using the regression model for automaticity. The second criterion was tested by constructing regression models with the motivation scores over time as the outcome. A similar backwards elimination process was conducted as above, and if time did not remain in the model, then the motivation variables was classified as not varying over time. The mixed effects models therefore served as tests of the different flossing intervention conditions, and as a screening mechanism to identify potentially relevant covariates that could only be properly investigated using SEM.

For the flossing analyis, simple SEM models were first constructed to see if each potential motivation predictor had an effect on behaviour, or automaticity (either directly or as an interaction with behaviour). In order to be able to investigate these models with the relatively small number of participants, separate models were constructed for each timepoint in the study. Those variables with significant pathways to behaviour or automaticity in the individual models were combined into a final model. The results for flossing and vitamin C are presented in separate chapters.

The final results chapter considers the impact of individual differences on habit formation. Measures were taken at baseline for personality, need for structure, prospective memory, and

rational or experiential thinking styles. In order to investigate whether these individual differences impact upon behaviour or automaticity, they were entered into the final regression models for both flossing and taking vitamin C tablets, and a backwards elimination procedure was used to exclude any non-significant variables.

2.9.2 Treatment of the variables

The distributions of all variables were checked for normality. The motivational variables which were skewed were categorised into three groups (as transformations could not improve the distribution sufficiently, and categorical variables would be easier to interpret). The first group included everything up to and including a mean score of four, as this includes everyone who does not agree to any extent with the statement. (This was on the whole the smallest group.) The next group consisted of those with a mean score greater than four, up to and including a score of six, which includes people who slightly agree or agree. The final group contained those with scores above 6, indicating more-than-agreement with the statement. These cut points are shown in Table 5. The categories were not set to ensure there were approximately equal numbers in each group as it is important that the different categories make sense theoretically. To avoid precision being affected by the smallest category (category 1), when these ordinal variables were used as covariates, the category indicating the highest score was used as the reference category.

Category	Lower cut point	Upper cut point
1	1	4
2	>4	6
3	>6	7

Table 5 Cut points for skewed variables transformed to categorical outcomes.

In order to be able to compare the T0 flossing rates (reported as average monthly rate), and the self-reported weekly rates at T1-T4, the T0 baseline rate was adjusted to an approximate weekly rate by dividing it by 4. The comparisons were made with T1 flossing rates at the target time of day only (i.e. evening or morning reported flossing rates).

2.9.3 Descriptive statistics and simple tests

The behaviour and automaticity outcomes were first explored using tables and graphs to look at patterns over time. Simple, paired t-tests indicated whether behaviour and automaticity increased from the point of the intervention to the end of the study. An ANOVA was conducted, using the factorial structure (two by two design) to examine simple main effects of the interventions (motivation Focus and flossing Placement) and their interactions, on flossing behaviour and automaticity.

2.9.4 Regression analysis of predictors of behaviour and automaticity

The main purpose of the regression analysis was to test the first and second hypotheses investigating the effect of placement in routine, and intervention focus, on behaviour and automaticity. The analysis also allowed predicted value graphs to be plotted, to illustrate the trajectory of behaviour and automaticity over time.

Regression model structure

The initial main analysis was conducted using regression models to look at predictors of the main outcomes of behaviour and automaticity over the course of the study. Longitudinal mixed models were fitted, in order to reflect the association between repeated measurements, within participants and households, using Restricted Maximum Likelihood (REML) estimation. These models contain a fixed part, which contain variables which may be predictive at a population level, and a random part for the effect of time, and to control for repeated measures within participants and households. This type of regression therefore allows separation of between and within subject effects, in order to better model the data.

Regression model contents

All theoretically plausible predictors were included in the fixed part of the equation (the random part of the model will be discussed below). This included time, the intervention conditions, age, sex, prior behaviour, and the baseline measurements of the various

motivation variables. Quadratic and cubic effects of time were included, as were two-way interactions between each of the three variables for time, and the two intervention conditions, and the set of three three-way interactions (time variables by Placement by Focus)[5]. While an interaction between the different condition (and therefore the three-way interaction) was not expected, it was included here for completeness, and to check whether the level of one category affected the outcome of the other category.

Models with motivation scores as outcomes

Although the effect of changing motivations over time on the outcomes of behaviour and automaticity is of primary interest, these models include predictors measured at baseline only. This is because variables measured following an intervention cannot be used as predictors in regression models, as they are affected by another variable under test. The investigation of these dynamic relationships was kept for later analysis using Structural Equation Modelling (SEM). In order to select variables to include in the flossing SEM, these were all also investigated as outcomes using mixed models (with a fixed part as above, but including only potentially related motivation variables.) The models of predictors of attractiveness and health motivations also investigated whether the Attraction versus Health interventions worked as expected to increase the related motivation scores, and whether this effect is mediated by the importance given to attractiveness and health (outcome evaluation items). Motivations which vary over time (or which remain in the regression predicting automaticity) were selected for investigation in the SEM model.

Baseline automaticity rates were not included in these regressions, as this would result in all data being excluded for those participants whose baseline scores were set to missing (for those who may have latent habits for the target behaviour). As these regressions are primarily being used to investigate potential variables for inclusion in SEM, the gain in precision through including participants who did not floss at baseline was held to be more important than the investigation of the impact of baseline automaticity on other variables.

[5] The data was collected every four weeks, at five time points starting from the beginning of the study; however, time was used in the models rather than "month" as many participants completed their questionnaires later than when they were sent, so the time since intervention is more precise. (Forty five questionnaires were completed over a week after they were sent.) Also, continuous time is more powerful than a categorical measurement of time (month), though it can be less flexible in modelling. However, by including quadratic and cubic effects of time, relationships within the data such as curves can be modelled by the regressions.

When ordinal variables are being used as outcomes, in addition to having categorical predictors, this leads to many combinations of values of the outcome and predictors which may have no observations. This phenomena, called intrinsic aliasing (McCullagh & Nelder, 1989), means that such complex models cannot be estimated from the data. To avoid this, unnecessary variables were removed, such as the interactions with quadratic and cubic time, the non-essential motivation variables, and sex, providing the initial Wald test showed that this was far from significance. The ordinal models for the motivation variables (which were split into three categories) had a multinomial distribution. These models also could not accommodate an extra random slope for household, so robust standard errors were then computed to allow for the slight misspecification of the model.

Treatment of time

For most of the analyses, time was transformed so that the time at T4 was coded as zero (and therefore the intervention for flossing occurred at minus 84 days, and the intervention for vitamin C occurred at minus 122 days). This meant that the parameter estimates could be interpreted as the effect of the variable at the final timepoint, when it is of most interest. However, the graphs of predicted values were plotted using the unadjusted scale of time since the intervention. The automaticity and stability models for flossing were constructed differently in order to allow for the missing values at baseline from people responding that they never perform the target behaviour. These models were not compatible with this adjustment for time, so in these cases the time variable in the regressions is the time since the intervention date. The intercept values therefore describe differences at the time of the intervention. A discontinuity was introduced to allow different slopes to be modelled before and after the intervention point. (This enabled inclusion of participants in the model who had missing scores at T0 or T1.) Only the effect of linear time was included at the point prior to the intervention, because as this parameter was estimated from only two timepoints (at T0 and T1), it was not possible to model a more complex slope.

Model assessment – random component

The fit of the model specification for the random component of the model was compared between different models using the likelihood ratio test (Rabe-Hesketh & Skrondal, 2008). The simplest random expression included the effect of both participant and household as random

intercepts (to allow parallel fit lines for each participant, along with clustering at the household level). The following model added a random slope for time (to allow the gradient to vary across participants), followed by quadratic and cubic time as random slopes (allowing the curvature of the slopes to vary across participants). The random slope components were included for the random intercept of participant only, not for household.

Model assessment – fixed component

Following the selection of the most appropriate random specification of the model for the data, the Wald test was used for backwards elimination on the fixed part of the model until all remaining variables had a significant Wald test value. The variables were first removed if the Wald test had $p>0.1$, and then once the model was refined, variables were excluded again using the cut-point of $p=0.05$. (Even though this analysis is largely exploratory, a more relaxed significance criteria was not selected, as many tests are being run.) The interaction effects were removed first, followed by the motivation variables, age and sex, baseline behaviour, intervention conditions (for the flossing data), baseline rate of outcome, and then time. (Though if a variable within one category seemed to be tending to significance, it was retained until other non-significant variables were removed, to allow for the possibility that the variable in question may achieve significance.) The three variables for time (the linear, quadratic and cubic terms) were tested simultaneously with the Wald test to see if there is a significant overall effect of time, but the parameter estimates were interpreted individually. If an overall significant effect of time is observed with the Wald test, however the individual parameter estimates were not significant, the cubic time (and if necessary, quadratic time) terms were removed from the model until the group and individual significance levels were consistent.

If the intervention Focus (Attraction versus Health) or flossing Placement (Before or After brushing) remains in the final flossing models, this indicates that the intervention groups had differential effects on behaviour and automaticity. The direction of any effect was examined to determine whether the first and second hypotheses are supported.

Statistical package

These regression analyses were conducted using SAS 9.3, as STATA makes assumptions about the denominator degrees of freedom which are inappropriate for models with many variables,

and small sample sizes, and leads to incorrect assessment of variable significance using the Wald test. STATA also tends to converge after too few iterations, which can affect the likelihood ratio test calculation if there are parameter estimates which are tending to zero. Therefore while most data manipulation and simple analyses were performed on STATA, the mixed model procedures were conducted on SAS.

2.9.5 Structural Equation Modelling – tests of dynamic predictors of habit formation, e.g. reward and motivation

Summary

Structural Equation Modelling (SEM) was used to measure the dynamic process by which automaticity changes over time. As the limited amount of data collected would not allow investigation of all the measured flossing covariates using SEM, the results from the analyses above allowed selection of only the potentially relevant covariates. These were variables which were observed to change over time, or which had baseline values which predicted later automaticity (as if a motivation variable is not a significant predictor at baseline, if it also does not change over time, it would not be expected to have any effect on later automaticity). The SEM analysis was conducted using STATA.

Model specification

As there were not a large number of observations, simple SEM models were constructed for each timepoint of the study, to determine predictors of automaticity at each point. By comparing the models at each point, comparisons can be made between the changing effects and parameters over time as automaticity develops. The first set of models for flossing tested each motivation variable individually, to assess whether it should be included in a more complete model. This first screening model included automaticity and behaviour, in the timepoint under investigation and the previous month, the effect of the two treatment conditions (as long as they are observed to have a significant effect in the regression analysis), and at least one motivation variable (plus any known confounders from the longitudinal regression for behaviour and automaticity). For each variable being considered as a potential predictor of automaticity, three paths were included to investigate different potential mechanisms to habit formation (MacKinnon, 2008). The three paths were: an effect on

automaticity mediated by behaviour, which is what is expected if automaticity is predicted by past behaviour frequency only (Triandis, 1977); an interaction, or moderation effect, modelled by an interaction term between motivation and behaviour, which is predicted by theories of reinforcement learning (de Wit & Dickinson, 2009; Dickinson, 1985); a direct effect from motivation to automaticity, which is unexpected theoretically, but which has been observed in other studies of habit (Judah et al., 2012; Wiedemann et al., 2014). These three pathways have been investigated in past habit research (Wiedemann et al., 2014). The variables were centred before computing the interaction term for the moderation effect, in order to reduce potential multicollinearity (Aiken & West, 1991).

An example of this simple model is shown in Figure 3 below. However it is important to note that conclusions regarding moderation and mediation are dependent on several assumptions that include no unmeasured confounding affecting any of the direct and indirect pathways studied, and also correct parametric model specification. The model was nevertheless developed with the intention of exploring the possible evidence of these pathways.

Flossing SEM – exploratory analysis

The first step for the flossing analysis tested all potentially relevant motivations individually, in order to refine the list by testing whether each had an effect on automaticity (via any one of the three pathways). Motivation variables that were observed to have an effect individually, were again tested in a model including direct and mediated effects for all other potentially effective motivations, to see which are likely to have an effect in an overall model. Following this, the motivation variables that were still potential predictors of automaticity were combined into a full model with all possible moderation and mediation effects. This full model was repeated for each timepoint, so that the predictors of automaticity and how these change over time could be investigated.

The flossing dataset contained missing values, which were due to amendments of the questionnaire measures following the start of the study, as described in section 2.8.5. The data could therefore be assumed to be Missing at Random, given that missingness was related to the study design. In order to avoid needing to exclude all incomplete records (which would potentially introduce bias), Maximum Likelihood estimation implemented via the EM algorithm was employed (Rabe-Hesketh & Skrondal, 2006) with the model specification including an indicator for the wave of data collection.

Vitamin C SEM – assessment of hypothesised rewarding variables

The model for vitamin C automaticity was not developed using this progressive screening approach. As there were specific potentially rewarding variables under test (as opposed to several variables being screened for their impact), the model was constructed, and tested individually with each reward variable. Again, this full model was repeated for each timepoint, so that the predictors of automaticity and how these change over time could be investigated.

Model fit assessment

Model fit was assessed in terms of the Comparative Fit Index (CFI) (Bentler, 1990), which represents the extent to which the target model is better than a model in which the variables are uncorrelated (the independence model). Values approaching 1 indicate acceptable fit. The CFI is not overly sensitive to sample size (Fan, Thompson, & Wang, 1999). Traditionally, the value of the CFI is recommended to exceed 0.93 in order for the model to be an acceptable fit (Byrne, 1994), however, the criterion can also be seen as more of a guideline (Bollen, 1989).

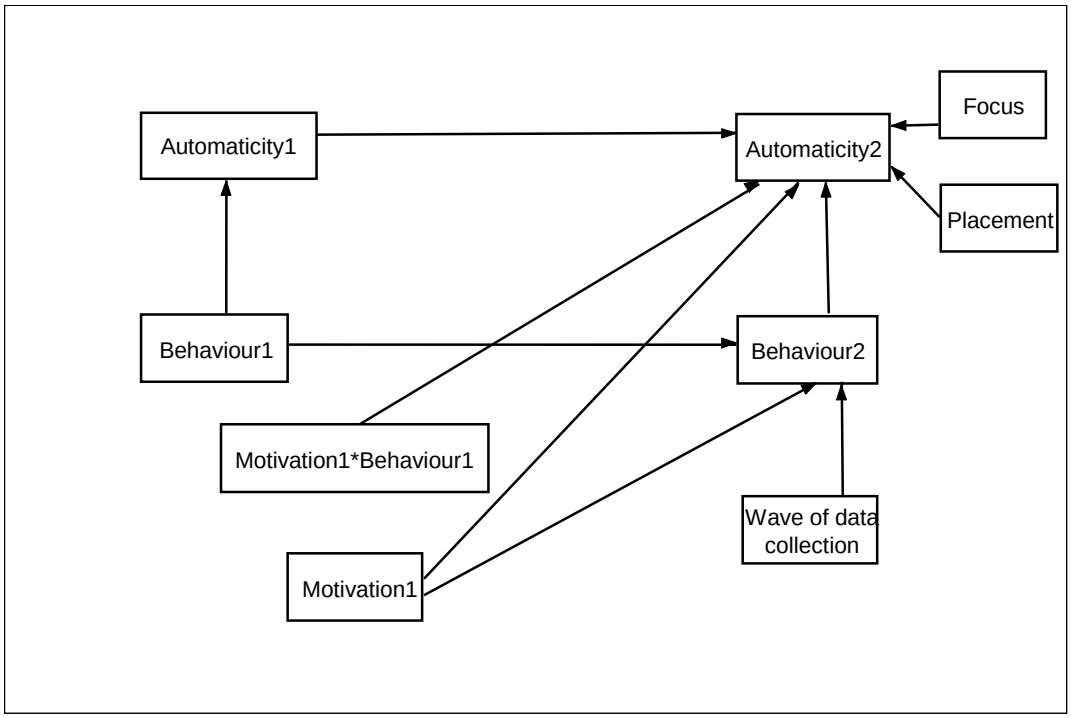

Figure 3 The outline model for the SEM analysis at T2
The model was adjusted according to the preliminary findings. Wave of data collection was only included in the models for flossing. Focus and Placement would only be included in the models for flossing if they were found to be significant in the regression analysis.

2.9.6 Testing effect of individual differences

The relationships between the individual difference scores measured at baseline were examined using a correlation matrix. The variables were added to the final regression models for behaviour and automaticity, for both flossing and vitamin C, to see if they have a significant impact when controlling for all other known variables. As with the earlier analysis, the individual difference variables were retained in the model if the Wald test had $p<.05$. Due to likely correlation between these variables, this will first be done with each individual difference measure individually, to examine the individual associations. In order to take into account any covariance, models were also constructed with all potential individual difference predictors, and refined using backwards elimination, until all non-significant variables were removed. Longitudinal regression analysis is appropriate for testing the effects of these variables, as they are measured once at the start of the study, and assumed to be constant over time. Therefore, they do not vary following the intervention delivery.

Chapter 3: Results – Effects of routine Placement and motivation Focus on flossing habit formation

Table of Contents

3.1 Introduction

In this chapter I investigate the results from the intervention on flossing behaviour and automaticity. While it has been discussed in greater detail in previous chapters, the background to this part of the study is summarised again here.

Past research on habit formation has demonstrated that there may be an effect of placement in a routine on automaticity, whereby flossing was more likely to become automatic if inserted after, rather than before toothbrushing (Judah et al., 2012). This was attributed to Event Segmentation Theory (Zacks et al., 2007), which holds that people build mental models of the world, which are rebuilt when they are no longer predictive, which is what occurs when one event finishes, and another starts. This point is known as an event boundary. Active memory is disrupted at event boundaries (Speer & Zacks, 2005; Swallow et al., 2009), which is expected to lead to implementation intention cues being less effective if they are based at the point of an event boundary rather than in the middle of an event. Furthermore, increased brain processing is observed at event boundaries (Fujii & Graybiel, 2003; Speer et al., 2007; Jeffrey Zacks, Braver, et al., 2001), suggesting that behaviour at this point may be less likely to be handed to automatic control.

For these reasons, it is expected that addition of a new behaviour to a routine is more likely to be performed, and to become automatic faster, if it is added within a chunk of activities rather than at the beginning of a chunk of activities. Participants flossing after they brush their teeth would therefore be expected to have greater gains in automaticity than those flossing before brushing. Even if brushing typically marks the end of the event, the addition of flossing would be expected to extend this event, as new events are characterised by goal or location changes (Hard et al., 2006; Speer et al., 2007) so neither of these are likely to occur between the activities of toothbrushing and flossing. Therefore, if flossing is inserted at the end of toothbrushing, and is cued by a prior-action at this point, the effect of the cue would not need to cross an event boundary. The effect of the placement of flossing before or after brushing on flossing behaviour and automaticity will be tested here, to confirm the findings of the initial study with a larger sample size and a longer monitoring period.

Another feature investigated in this study was whether attractiveness is a better motivator of behaviour than health. The effect of attraction has been shown to change behaviour (Raska & Nichols, 2012) and has been used to market products (Colarelli & Dettmann, 2003; Till & Busler, 2000). That attraction should be an effective driver of behaviour is theoretically expected by the Evo Eco model (Aunger & Curtis, 2013), which holds that motivations are a more proximal cause of behaviour than plans such as health. A focus on attractiveness is a strategy that has even been employed in the marketing of commercial products relevant to health, such as soap (O'Connor, 2014). It is therefore expected that interventions based on attraction, as opposed to health, may lead to both greater gains in behavioural frequency, and also be more reinforcing, thereby leading to greater increases in automaticity.

Satisfaction is held to be an important predictor of behavioural maintenance (Rothman, 2000). However, it is not always clear what may count as satisfaction in this context, and whether features like satisfaction may have an impact beyond repetition, in predicting greater gains in automaticity. For example, attitude was observed to predict higher levels of automaticity in the past study on flossing habit formation (Judah et al., 2012). Therefore, this study will also include exploratory analysis to test the effects of motivational variables, such as TPB variables, and perceived rewards on both behaviour and automaticity.

This study is testing the following hypotheses:

H1: Inserting a new behaviour in the middle or end, rather than at the beginning of a behavioural event is more likely to lead to habit formation.

H2: Interventions based on sexual/social attractiveness (a basic human motivation) will be more effective in promoting behavioural automaticity than interventions focussing on plans to improve health.

H3: Reward will moderate the behaviour-automaticity gain relationship, by leading to greater increases in automaticity for each behaviour repetition.

3.2 Methods

A face-to-face intervention was delivered at T1 (four weeks after the start of the study), to allow participants time to adjust to the monitoring equipment that was installed. The intervention consisted of: participants describing in detail their evening routine, so that it could be seen specifically how flossing could fit into their own idiosyncratic routine; a leaflet including information about why, when and how to floss, which was talked through with the participant (shown in Appendix 1); participants were then guided in forming an implementation intention based on their own idiosyncratic routines, which they wrote down as part of a pledge to try to floss every day.

Participants were randomly assigned to different types of intervention, each of which had two conditions (hence a two-by-two design resulting in four groups). Randomisation occurred at the household level. The first intervention modified the placement of flossing in the routine either before or after toothbrushing (the Before TB group and the After TB group). Participants were assigned to placement groups by giving them reasons (within the intervention leaflet) why it is best to floss teeth either before or after toothbrushing (there are

reasons for both seen in the dental literature), and getting them to form an implementation intention which is specific to the point in their routine required by their intervention assignment.

The second intervention aspect was investigating the effect of an intervention focussed on attraction versus health. This Focus condition was assigned by having the leaflets designed with the "why to floss" sections targeted either to how flossing makes your teeth look nicer and breath better (Attraction group), or how flossing is good for your dental health (Health group). The pictures reflected this, and were either of smiling people and couples, or of teeth and dentists. The interventions are described in more detail in the Methods chapter, in line with the TIDieR intervention description checklist (Hoffmann et al., 2014), and the Behaviour Change Technique Taxonomy (v1) (Michie et al., 2013).

Participants completed questionnaires every four weeks of the study including questions on self-reported flossing frequency in the past week, automaticity and context stability for flossing, and different motivation questions about flossing.

3.3 Analysis

The analytic procedure is described in greater detail in the Methods chapter, but summarised again below. There were four main stages to the analysis: 1) descriptive statistics: 2) simple analyses of the two hypotheses tested related to the intervention assignment; 3) regressions investigating baseline predictors of the different outcomes and covariates, and to test the effects of the intervention conditions; and 4) structural equation modelling (SEM) to look at dynamic predictors of behaviour and automaticity over time.

3.3.1 Preliminary analysis

Checks of the data and treatment of variables

The distribution of all variables was checked for normality. Variables that were not normal were turned into ordinal variables by splitting them into three categories. The continuous covariates are: context stability[6], attractiveness motivation, experiential attitude, descriptive

[6] While context stability scores were observed to be skewed, due to missing baselines (from participants reporting that they never floss at baselines) the analysis was more complicated, and time pressures did

norm, subjective norm, hassle, punishment and reward. The ordinal covariates are: health outcome evaluation and attractiveness outcome evaluation, intention, health motivation, instrumental attitude, and perceived behavioural control.

Participants were asked to try and floss in the evening. Separate questions for automaticity and self-reported behaviour were asked for flossing in the morning or evening. As context is important for developing habits (Lally & Gardner, 2013; Lally et al., 2010) only the automaticity and behaviour scores in the evening were considered in the analysis. For those who decided at the intervention to floss in the morning (as this was more convenient for them), their morning flossing behaviour and automaticity for morning flossing scores were considered instead. Therefore, variables were created for behaviour and automaticity at the target times (evening for most participants, but morning for some). The variables discussed in the analysis below for behaviour and automaticity refer to these scores at the target times only.

Correlations between covariates

Correlations between all motivation variables and covariates are presented, along with correlations with behaviour at and automaticity at T4, to see how the variables were associated with one another. The magnitude of strong correlations were identified (Cohen, 1992).

As shown in Table 6, many of the motivation items were significantly correlated. Generally, the correlations between automaticity and the motivation variables are stronger than those between behaviour and the motivation variables. The only motivation variables than do not significantly correlate with automaticity are health outcome evaluation and PBC. Automaticity correlates strongly with behaviour, subjective norm, experiential attitude and reward. Both automaticity and behaviour correlate strongly with intention. The strongest correlations were observed between reward, experiential attitude and attractiveness motivation. Health and attractiveness motivation were strongly correlated, as were health outcome evaluation and attractiveness outcome evaluation. Descriptive and subjective norm were also very highly correlated.

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not allow this to be developed further for a categorical analysis. However, as the purpose of this stage of analysis was mainly to see whether each potential covariate varies over time and should therefore be included in the SEM analysis, doing this analysis was deemed sufficient even though the assumption of normality was not met. The non-normality of the data is not problematic for explanatory variables in SEM.

	1#	2#	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Behaviour#	1														
2. Automaticity#	**.603*** **	1													
3. Context stability	.470***	.438***	1												
4. Attractiveness motivation	.175	.464***	.276***	1											
5. Descriptive norm	.206*	.493***	.230***	**.531*** **	1										
6. Subjective norm	.231*	**.529*** **	.159**	**.545*** **	**.745*** **	1									
7. Experiential attitude	.426***	**.615*** **	.376***	**.537*** **	.395***	.405***	1								
8. Reward	.462***	**.674*** **	.398***	**.646*** **	**.502*** **	**.525*** **	**.825*** **	1							
9. Punishment	-.231*	-.269***	-.202***	-.258***	-.076	-.049	**-.508*** **	-.412***	1						
10. Hassle	-.286**	-.336***	-.100*	-.158***	-.168***	-.059	-.327***	-.304***	.474***	1					
11. Health outcome evaluation[ɣ]	.111	.156	.155**	.256***	.079	.141**	.282***	.279***	-.246***	-.087	1				
12. Attractiveness outcome evaluation[ɣ]	.170	.269**	.154**	.308***	.119	.196***	.377***	.382***	-.318***	-.154**	**.560*** **	1			
13. Intention[ɣ]	**.504*** **	**.507*** **	.345***	.422***	.293***	.324***	.450***	**.580*** **	-.240***	-.116*	.316***	.405***	1		
14. Health motivation[ɣ]	.137	.335***	.265***	**.540*** **	.242***	.297***	.358***	.414***	-.231***	-.009	.389***	.344***	.353***	1	
15. Instrumental attitude[ɣ]	.107	.201*	.272***	.418***	.127*	.194***	.350***	.391***	-.319***	-.100	.272***	.290***	.391***	.425***	1
16. PBC[ɣ]	.147	.095	.175***	.071	.115*	.052	.176***	.209***	-.165**	-.145**	.198***	.267***	.286***	.155**	.180***

Table 6 Pairwise correlations between all flossing motivation variables.
All correlations greater than 0.5 are seen as large correlations, and marked in bold (Cohen, 1992).
 # Correlations with behaviour and automaticity are conducted at T4 only.
[ɣ] indicates ordinal variables, and therefore all correlations with these variables are with Spearman's rho.
** p<.05, ** p<.01, *** p<.001*

3.3.2 Descriptive statistics and simple group comparisons

The rates for flossing behaviour and automaticity were plotted descriptively using bar graphs by group and over time, in order to become familiar with the general qualities of the data and any group differences. An ANOVA was used to determine whether there were significant group differences in the change scores for behaviour or automaticity between the beginning and end of the study, before any covariates were taken into account.

Simple t-tests were conducted comparing the attractiveness and health motivation scores over time between groups, in order to assess the effectiveness of the Attraction and Health interventions in changing the relevant motivation scores. This question was also assessed using the regressions described below.

3.3.3 Regressions of baseline predictors of all variables

The regression analyses allow investigation of the impact of the intervention conditions on flossing behaviour and automaticity, accounting for covariates. The first main analysis was conducted using longitudinal mixed effects models (that allow for both fixed and random effects) to allow for repeated measures of the outcomes over time, within participants and households. As post-intervention variables cannot be included in these models, as they are likely to be affected by another variable under test (e.g. group), these regressions models included baseline predictors only (Pearl, 2000). The predictors were the two intervention assignments (Placement and Focus), all the motivational variables, context stability, as well as age and sex. The initial model also included attractiveness outcome evaluation and health outcome evaluation scores, and the interaction of each of these with the Focus group and time, to control for whether the Focus assignment had an impact moderated by the importance given to having attractive teeth, or good dental health (and whether that effect changed with time since the intervention).

The model was refined using a backwards elimination procedure using the Wald test, to exclude variables that do not contribute significantly to the model, until a final model is reached. This was used to determine whether the intervention assignment was a significant predictor of flossing behaviour or automaticity, and therefore to address the main hypotheses of this chapter. The hypotheses were assessed according to whether the Placement and Focus variables (indicating intervention group assignment) remained as significant predictors in the

final model. The predicted values of behaviour and automaticity were plotted, to illustrate how the variables change over time.

As the effects of the covariates throughout the study are of interest, as well as testing the effects of the interventions, this regression analysis was used to screen variables which are of potential importance for the habit formation process. These variables were investigated using SEM, which can look at later predictors of the outcomes.

The first criterion for inclusion in the SEM analysis was whether the baseline measurement of the covariates predicted later automaticity in the regression analysis. Each of the covariates were then entered as the outcome in a regression containing the baseline score for that variable and any related variables, baseline behaviour, context stability and time. A backwards elimination procedure was used again to refine the model, and variables which retained time as a predictor in the model for the scores throughout the study (and therefore were shown to change over time) were retained for analysis using SEM.

In summary, for a variable to be included in the SEM analysis, it must either have a baseline value which predicts automaticity over the study, or the value of the variable must change significantly over time. This is because, if a variable at baseline was not predictive of later automaticity, and if the variable did not change over time, then its measurement at a later timepoint could not be a predictor of automaticity.

3.3.4 Structural Equation Modelling

Basic Structural Equation Models were constructed to further refine which variables should be included, until a final model is developed. Due to constraints in the sample size, separate models were constructed for each timepoint. The first level of screening includes each motivation variable separately within the basic model, to test whether there are any significant effects of the motivation variable at test. The basic model includes current and prior automaticity and behaviour, the two intervention assignments (if these were found to be significant in the regression analysis), and three different paths from the motivation variable to automaticity (direct, mediated by behaviour, and moderation of the behaviour-automaticity relationship). The variable of wave was also included, to account for the slight amendments to the variables being measured following the first wave. An example of the basic model for T2 is shown in Figure 4.

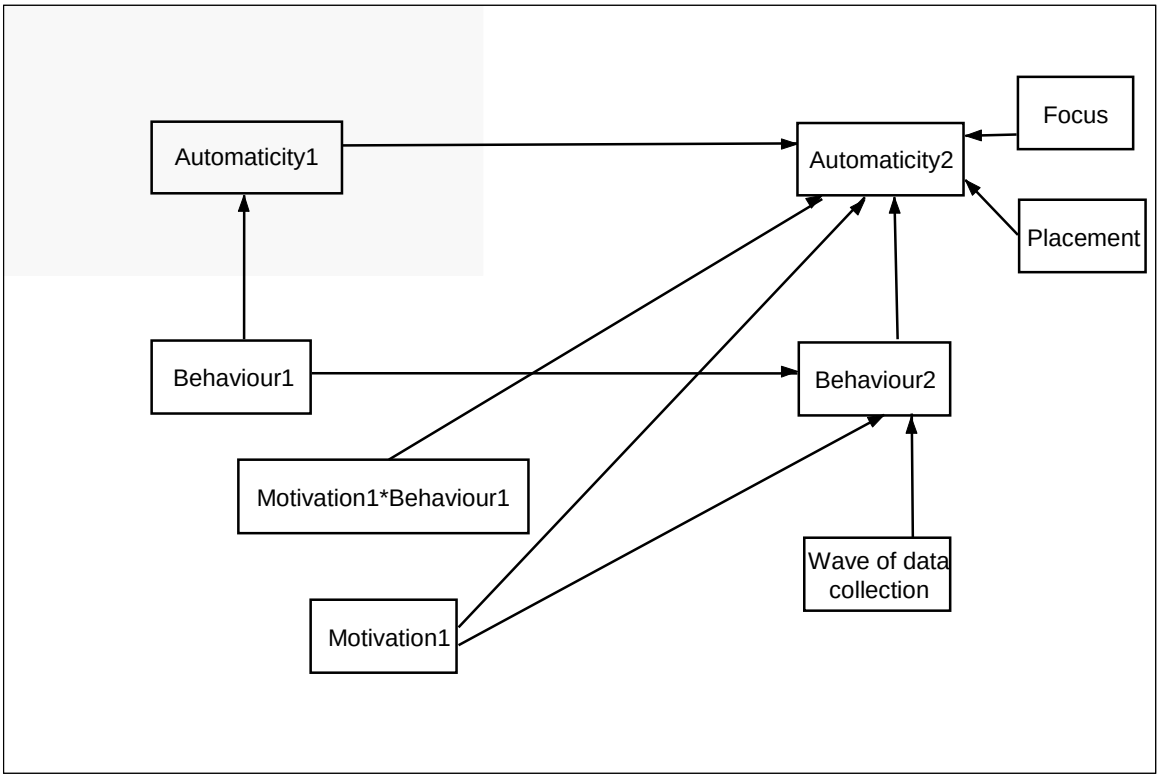

Figure 4 Basic screening model for T2
If the intervention variables of Placement and Focus were found to be significant from the regression analysis, these would be included as predictors of automaticity. The wave variable is included in order to improve the missing values estimation due to the missingness due to amendments to the study design after the first wave of data collection.

Motivation variables with at least one significant pathway from the first level of screening were all combined into a second level screening model. The selected motivation variables were all included as predictors of behaviour, and also automaticity (if they had a significant effect on automaticity in the first level screening models). One variable at a time was tested with all three paths described above (mediation, moderation and direct effect). Variables which retained any significant paths when controlling for other potential covariates were retained to the full model.

Theoretically expected refinements were made to the full model in order to improve the fit, such as pathways between different covariates, e.g. from motivation to intention. The final model was examined at each timepoint. Moderation effects were plotted using a simple slopes analysis in order to visualise any effects (MacKinnon, 2008).

3.4 Results

3.4.1 Participants

122 participants were enrolled on the study and completed the T0 procedures, however four dropped out before the intervention session at T1. This left 118 participants (65 women), mean age=35.7, SD=11.8. Of these, a further four did not complete the study, but all data that was collected for these participants was retained in the analysis.

When examining the different groups, they were on the whole well balanced according to the number of participants in each group, age and sex (see Table 7). However, the Health group did have participants that were significantly older than the Attraction group, $F(1,114)=8.91$, $p=0.004$. Therefore, age was controlled for in the analysis. There were no significant differences in ages between the Before TB and After TB groups, and no significant interaction between the groups. A logistic regression revealed no significant differences in the number of men across the different groups. Nonetheless, both age and sex were included in the regression analyses.

The two by two design resulted in four different treatment groups. These are:

Before TB, Attraction group (when Placement = Before brushing, and intervention Focus = Attraction)

Before TB, Health group (when Placement = Before brushing, and intervention Focus = Health)

After TB, Attraction group (when Placement = After brushing, and intervention Focus = Attraction)

After TB, Health group (when Placement = After brushing, and intervention Focus = Health)

Key: n Mean age (SD) % women	Before TB	After TB	Focus total
Attraction	**Before TB, Attraction group** 32 33.0 (10.2) 56%	**After TB, Attraction group** 29 32.2 (9.5) 59%	61 32.6 (9.8) 57%
Health	**Before TB, Health group** 27 35.9 (11.5) 59%	**Before TB, Health group** 30 41.8 (13.6) 47%	57 39.0 (12.9) 53%
Placement total	59 34.4 (10.8) 58%	59 37.1 (12.6) 53%	118 35.7 (11.8) 55%

Table 7 Group composition by age, sex and number of participants.

3.4.2 Descriptive statistics

Descriptive statistics of flossing behaviour across groups over time

Simple t-tests indicated that considering all participants together, increases were seen from T1 to T4 in behaviour ($t(88)=8.29$, $p<.001$), with mean weekly behaviour scores rising from 1.66 to 4.18.

Visual examination of Figure 5 reveals that all groups showed a small increase in flossing frequency between T0 and T1, just since being registered in the study, having the equipment set up and completing the baseline measures. The After TB, Attraction group shows levels very different to the other three groups. The After TB, Health group showed the biggest increase from T0 to T1, and the After TB, Attraction group showed the smallest increase. This pattern of the relative mean flossing frequencies between groups persists throughout the study. The After TB, Attraction group again showed a relatively modest increase in mean frequency by the T2, which remains constant throughout the rest of the study. Both Before TB groups had a large mean increase by T2, and declines over T3 and T4. The After TB, Health group showed a similar large mean increase, but much smaller declines through the rest of the study.

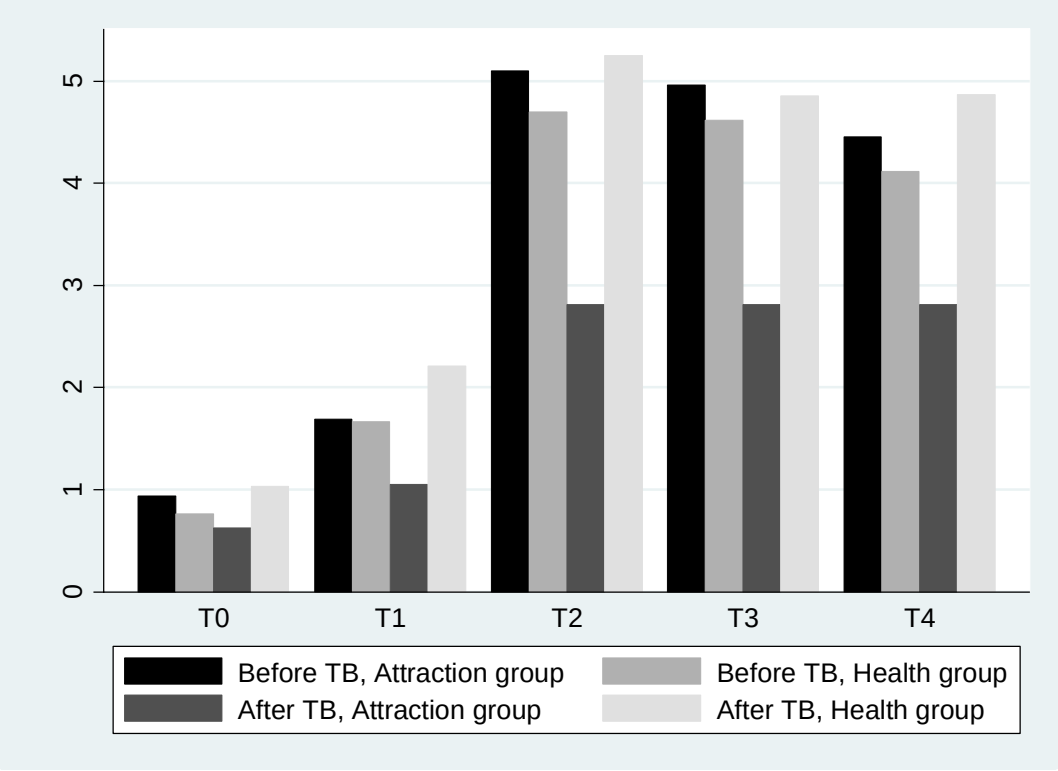

Figure 5 Bar graph of mean weekly flossing behaviour by group over time [7]

	Health			Attraction			Total	
Timepoint	**After TB**	**Before TB**	**Total**	**After TB**	**Before TB**	**Total**	**After TB**	**Before TB**
T0	0.67	0.67	0.67	0.45	0.66	0.56	0.56	0.66
T1	0.81	0.85	0.83	0.69	0.68	0.68	0.75	0.76
T2	1.00	0.96	0.98	0.89	1.00	0.95	0.94	0.98
T3	0.96	0.96	0.96	0.89	1.00	0.95	0.93	0.98
T4	0.97	0.92	0.95	0.89	0.97	0.93	0.93	0.95

Table 8 Proportion of people who report "ever flossing" by intervention group and time

Table 8 shows the proportion of people in each group who report that they "ever floss", through giving responses to the SRBAI that are not "N/A, I never floss my teeth...". At T0, the After TB, Attraction group had only 45% of participants who reported ever flossing. The other groups all have two thirds of participants who report ever flossing. By the intervention month (T1), both Health groups had over 80% participants who report ever flossing. The After TB, Attraction group had the same proportion of people ever flossing as the Before TB, Attraction

[7] As stated in the methods chapter, the T0 rate was calculated by dividing the total monthly amount for baseline by four, and the rates for T1 onwards were the past week flossing frequency for the target timepoint only.

group (just over two thirds). For the rest of the study, the After TB, Attraction group had an "ever floss" rate of 89%, while the rest of the groups have rates of nearly 100%. The lower rates found in the After TB, Attraction group is consistent with what is observed in the bar charts of self-reported flossing frequency.

Descriptive statistics of flossing automaticity across groups over time

A simple t-test of changes in flossing automaticity across all participants revealed significant increases in automaticity scores between the intervention and the end of the study ($t(108)=7.82$, $p<.001$), with mean scores rising from 2.12 to 3.69.

The bar graph in Figure 6 showing the mean rates of flossing automaticity between groups reveals a slightly different pattern to the bar graph of mean behavioural frequency (Figure 5). At baseline the After TB, Attraction group had a much lower mean automaticity rate than all the others. The different groups show different patterns of increases, though these are not consistent with the hypothesised patterns of the After TBs group showing greater increases than the Before TB group, or the Attract groups performing better than the Health groups. The patterns observed so not show any clear pattern of either intervention condition (for either Focus or Placement) having an advantage over the other.

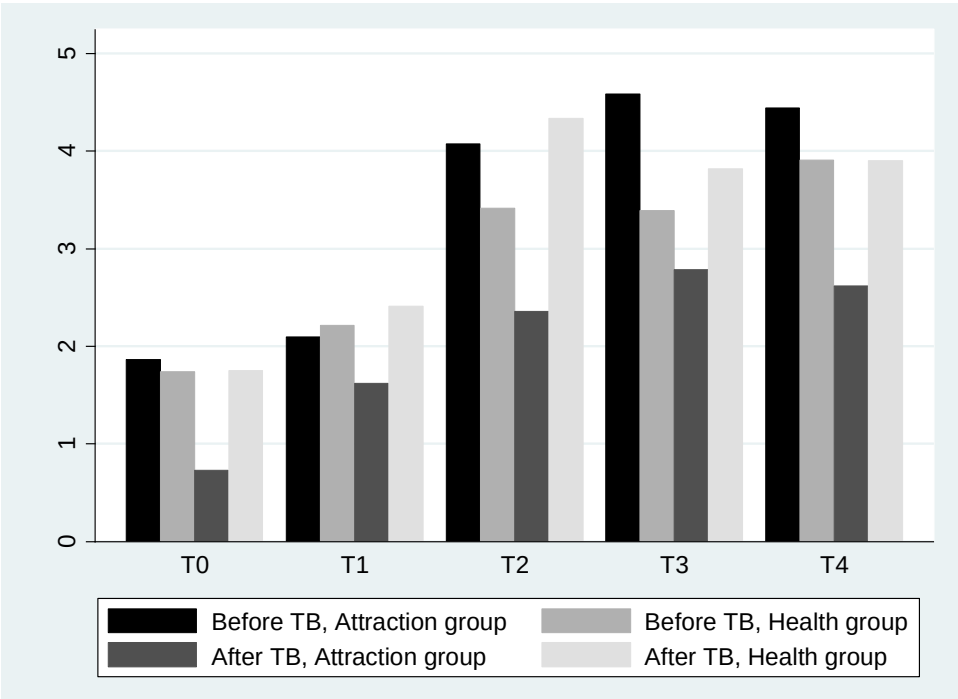

Figure 6 Bar graph of mean target automaticity by group over time

Descriptive statistics: Group comparisons

The After TB, Health group showed a significant increase in behaviour[8] (t(23)=2.6 p=0.016) and automaticity (t(20)=2.3 p=0.024) between T0 and T1 (from the baseline session to the intervention session). The After TB, Attraction group showed a significant increase in automaticity (t(28)=3.0 p=0.006). While these groups showed a significant increase in automaticity, all groups received the same treatment prior to this point, so these differences were assumed to be due to chance. Baseline rates are controlled for in the later analyses, so these differences are taken into account.

3.4.3 Simple tests of intervention group differences

The change in automaticity scores and self-reported behaviour between the intervention and the end of the study (T1-T4) was compared across groups using an ANOVA, to investigate the effect of group according to the two by two factorial design (i.e. both the main effects of each group, and interaction).

Simple group differences between the Before TB and After TB groups

There were no group differences in behaviour score increases (p=0.61). The Before TB group showed significantly greater increases in automaticity than the After TB group, with difference scores of 2.03 and 1.08 respectively F(1,104)=5.89, p=0.017. This is contrary to the first hypothesis of the study, whereby it was expected that the After TB group would show higher levels of behaviour and automaticity compared to the Before TB group.

Effectiveness of the Attraction and Health interventions in affecting motivation

As a check of the Focus intervention, it was investigated whether the Attraction versus Health intervention had differential effects on the relevant motivations. This was investigated using simple checks, to see how the interventions affected the baseline scores for the attractiveness

[8]The baseline behaviour rate was calculated as the monthly rate given divided by four, yet in the second questionnaire, this was the behaviour at the target time only, so is a slightly different measurement. A significant difference was still not seen in the other groups.

and health motivations, and how long any effect was seen to last. In order to do this, difference scores were calculated between the baseline attractiveness and health motivation scores, and the scores at later months. Two sample t-tests were conducted to see whether there were group differences in those motivation difference scores. For the attractiveness motivation scores, there were no significant differences between the groups, even just after the intervention, t=-0.54, p=0.59. Table 9 shows that the Health group showed a greater increase in health motivations than the Attraction group immediately after the intervention (T1), t=2.10, p=0.038. This group difference only showed borderline significance by T2, but the differences were no longer significant following this. Therefore, the Attraction condition did not appear to be effective in differentially increasing attractiveness motivation, whereas the Health condition worked to increase health motivation more than for the Attraction group, but only for a short time period.

Difference	Attraction group	Health group	Group difference	p
T1-T0	0.131	0.386	0.255	0.038*
T2-T0	0.169	0.429	0.259	0.051
T3-T0	0.155	0.351	0.196	0.155
T4-T0	0.121	0.321	0.201	0.134

Table 9 Difference scores in health motivation between the baseline and later months, separated by Attraction and Health intervention groups.

Interestingly, while there were significant differences for the health motivation scores at the beginning of the study, the differences themselves were very small. Over the duration of the study, the mean difference between monthly and baseline scores was only 0.202 (SD=0.636). The attractiveness motivation showed larger score increases, though as described above, these did not show significant group differences, mean=0.412 (SD=1.1).

Simple tests of group differences between the Attraction and Health groups

There were no group differences in change in behaviour (p=0.63) or automaticity (p=0.86) between the Attraction and Health groups. This is contrary to the second hypothesis of the study, whereby it was expected that the Attraction group would show higher levels of behaviour and automaticity compared to the Health group. However, the lack of group

differences in attractiveness motivation, and the small and temporary difference in health motivation suggests that Hypothesis 2 may not have been supported because the intervention did not facilitate the desired effects on the attractiveness and health motivation levels of the two groups.

There was no significant interaction between the Placement and Focus group assignments for behaviour (p=0.23) or automaticity (p=0.16).

3.4.4 Regression analysis

A backwards elimination regression procedure was conducted for the outcomes of behaviour and automaticity, as well as context stability. Graphs of predicted values are plotted to illustrate changes over time.

Test of H1 and H2 with baseline predictors of flossing behaviour

		Regression of flossing behaviour			
Predictor		**B**	**SE**	**p**	**Wald test, p**[9]
Intercept		1.257	0.744	0.094	
Time group					<.001
	Adj time	0.018	0.018	0.312	
	Adj time squared	17.1~	5.84~	0.004	
	Adj time cubed	0.22~	0.047~	<.001	
Age		0.036	0.015	0.017	
Baseline reward		0.392	0.125	0.002	

Table 10 Final model of self-reported flossing behaviour.
A random slopes model was used. Adjusted (Adj) time= time minus 84 days, so the intervention occurs at -84 days, and the intercept and parameter estimates represent differences at the end of the study.
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

[9] As the linear, quadratic and cubic effects of time are included in the model, and tested for their inclusion in combination using the Wald test, in these cases the Wald test is different from the p values of the individual time variables in the final model. Therefore, for the Wald test of the combination of time effects, and for the interaction terms, the Wald test p value is cited in the tables in order to indicate whether the parameter estimates for the individual variables should be interpreted as being important in the model.

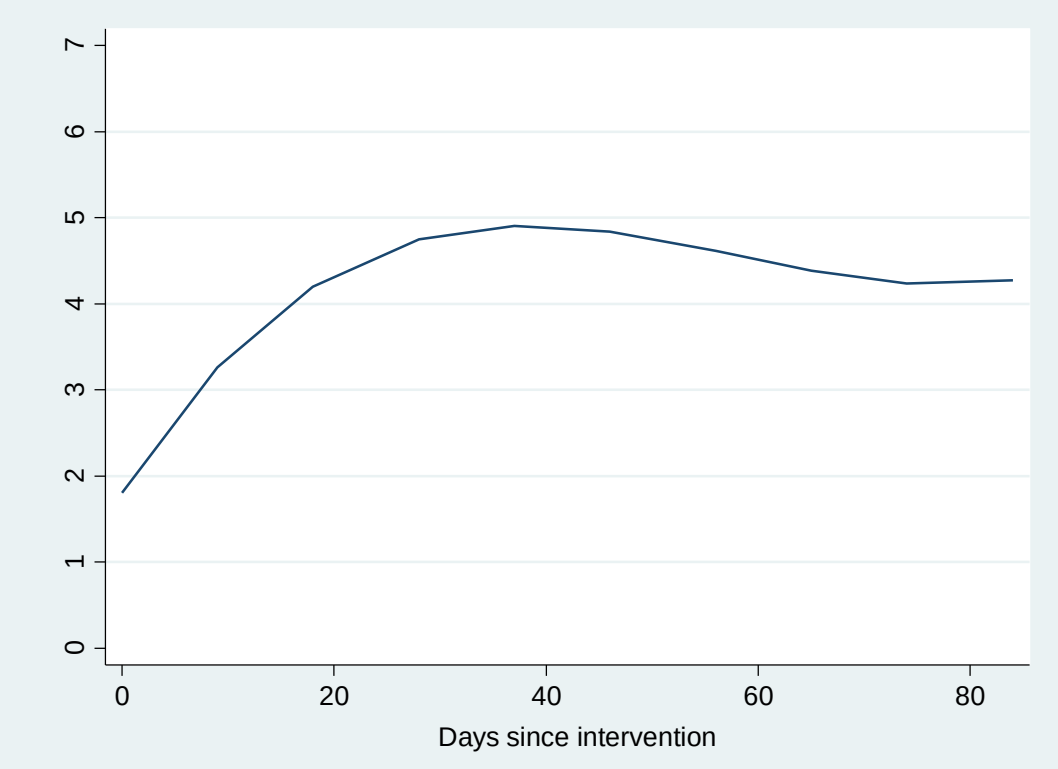

Figure 7 Graph of predicted values of flossing behaviour.
The graph depicts predicted values for a participant aged 40 years, and with a baseline reward score of 4.

The final model for flossing behaviour is shown in Table 10. There is no evidence of an effect of the intervention groups on behaviour over the course of the study, as these were excluded from the model by the Wald test. For each additional year of age of the participant, a 0.036 increase in final weekly behaviour frequency was observed (p=.017). Baseline reward scores were positively related to behaviour frequency (b=0.392, p=.002). From Figure 7 modelling the predicted values for behaviour (a hypothetical graph based on the final model, as opposed to the actual data), a steep increase following the intervention to the second measurement point can be seen, followed by a small gradual decline over the rest of the study, which plateaus towards the end.

Sensitivity analyses were conducted for the main outcomes of behaviour and automaticity. This excluded fourteen participants from the analysis[10]. The final model for behaviour was the

[10] Six participants had their intervention session over a week after the ideal date due to being on vacation (range 9 days - 17 days late). Two participants already used interdental sticks daily from before the study starts, and were not prepared to try flossing instead. Two participants asked to use floss picks instead either as they find it easier, or in one case due to arthritis making it hard to use regular floss. As this is slightly different to regular floss, and is something that some other people may have preferred to use for other reasons, it is possible that participants who used these should perhaps be excluded. One household had searched for the researcher online, and so knew the study was about habit formation, and also had read the paper which would lead them to suggest that they had been assigned to the Placement condition hypothesised to be less effective. One participant was assigned to the "After TB" group, but formed an implementation intention linking flossing to the beginning of the routine, by

same as that reached from the full dataset, indicating that the participants excluded do not change the findings, and so could be kept in the main analysis.

The fact that the group variables of Placement and Focus were not retained in the final model suggests a lack of support for the first and second hypotheses, as there is no differential impact of interventions based on attraction versus heath, or flossing before versus after brushing, on flossing frequency. However, the null finding for the Attraction versus Health intervention likely reflects the inability of the intervention to have the desired effect on the attractiveness or health motivations.

Test of H1 and H2 with baseline predictors of flossing automaticity

Unlike the behaviour regression, the regressions for automaticity and stability were conducted with unadjusted time, so the parameter estimates indicate effects at the point of the intervention[11]. The final model is shown in Table 11. Age was positively associated with automaticity (b=0.029, p=.004). As were baseline descriptive norm (b=0.237, p=.007), and baseline reward (b=0.344, p<.001). In the sensitivity analysis, age was removed from the model as not being significant, but the model is otherwise the same. As this is not an important difference, the full dataset was still retained for the analysis.

Figure 8 illustrates the predicted values for flossing automaticity over time. This illustrates that automaticity appeared to change between T0 and T1, before the intervention. This automaticity increase appeared faster following the intervention, until it plateaued approximately 60 days after the intervention. A small decrease in automaticity was then observed. Individual graphs for each participant, comparing the fitted and observed values for flossing behaviour and automaticity over the course of the study, are shown in Appendix 8.

As the variables for the Focus and Placement assignments were excluded from the model using the Wald test, the groups were observed not to have differences in automaticity scores at the point of the intervention. The exclusion of the interaction terms between the Focus and Placement variables with time indicates that there were no significant differences in the trajectories of automaticity gain over time between the different groups. This is evidence

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deciding to take a piece of floss as a reminder as soon as she enters the bathroom, before she brushes her teeth. Another household were assigned to the After TB group, but were mistakenly given leaflets for the Before TB condition, however it did not seem that they noticed the discrepancy.

[11] Due to the exclusion of early (baseline and month 1) automaticity and stability results if participants reported never flossing but having flossed before, the resulting missing values meant that baseline automaticity values could not be included in the normal way without excluding a high proportion of participants. The model was instead constructed with a discontinuity at the point of the intervention.

against hypotheses 1 and 2. Neither the first hypothesis (that the After TB group will show greater increases than the Before TB group) nor the second hypothesis (that the Attraction group will show greater increases in automaticity than the Health group), were supported.

Predictor		Regression of flossing automaticity			
		B	**SE**	**p**	**Wald test, p**
Intercept		-1.042	0.489	0.035	
Time (pre intervention)		0.019	0.006	0.001	
Timegroup (post intervention)					0.001
	Time	0.095	0.016	<.001	
	Time squared	-17.6~	4.72~	<.001	
	Time cubed	0.10~	0.036~	0.005	
Age		0.029	0.010	0.004	
Baseline descriptive norm		0.237	0.085	0.007	
Baseline reward		0.344	0.089	<.001	

Table 11 Final model of flossing automaticity
A random slopes model was used. The time variable is the number of days since the intervention, and therefore the parameter estimates reflect differences at the point of the intervention.
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

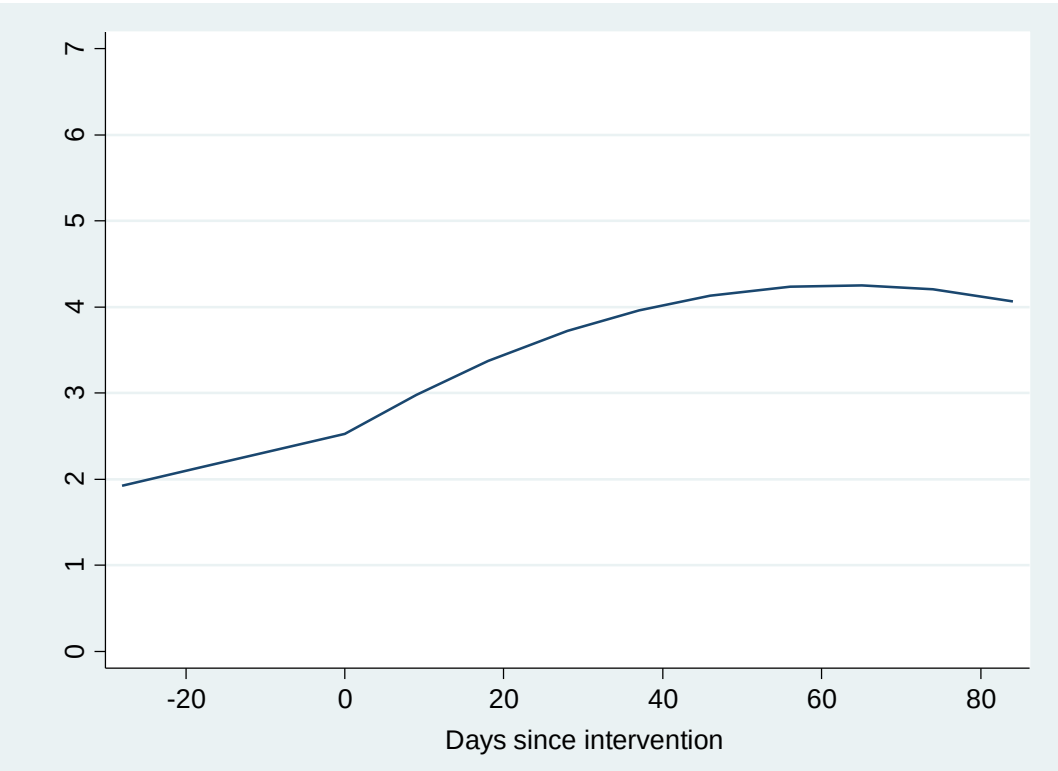

Figure 8 Graph of predicted flossing automaticity
The graph depicts a participant assuming an age of 40 years, a baseline reward score of 4 and a baseline descriptive norm score of 4.

Test of the baseline predictors of context stability

This analysis was conducted to investigate whether the Before TB and After TB group assignments had an impact upon context stability of flossing performance. Due to the similarity in structure of the context stability to the automaticity measure, the analysis was conducted in the same way (with the intercept at the point of the intervention, and a discontinuity of the trajectory at this point.) The model is shown in Table 12. There was no differential effect of any of the intervention groups, suggesting that they do not differ on their context stability scores, either at baseline, or later in the study. There was a small increase in stability over time before the intervention. Following the intervention, there appears to be a sharper increase in stability scores. The increase in stability plateaued at around 30 days following the intervention, and then fell slightly before levelling off again. Baseline flossing frequency was associated with higher stability (b=0.139 p=.036). In the sensitivity analysis, the effect of cubic time was removed, but the model was otherwise not affected.

The trajectory of context stability scores over the course is the study is shown in Figure 9. The scores rose from the start of the study, and this rate of increase continued past the point of the intervention. The values started to fall again slightly from approximately 30 days following the intervention.

		Regression of flossing automaticity			
Predictor		**B**	**SE**	**p**	**Wald test, p**
Intercept		3.498	0.282	<.001	
Time (pre intervention)		0.030	0.010		
Timegroup (post intervention)					<.0001
	Time	0.139	0.024	<.001	
	Time squared	-29.0~	7.40~	<.001	
	Time cubed	0.17~	0.057~	0.002	
Baseline flossing		0.139	0.036	<.001	

Table 12 Final random slopes model of flossing stability
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

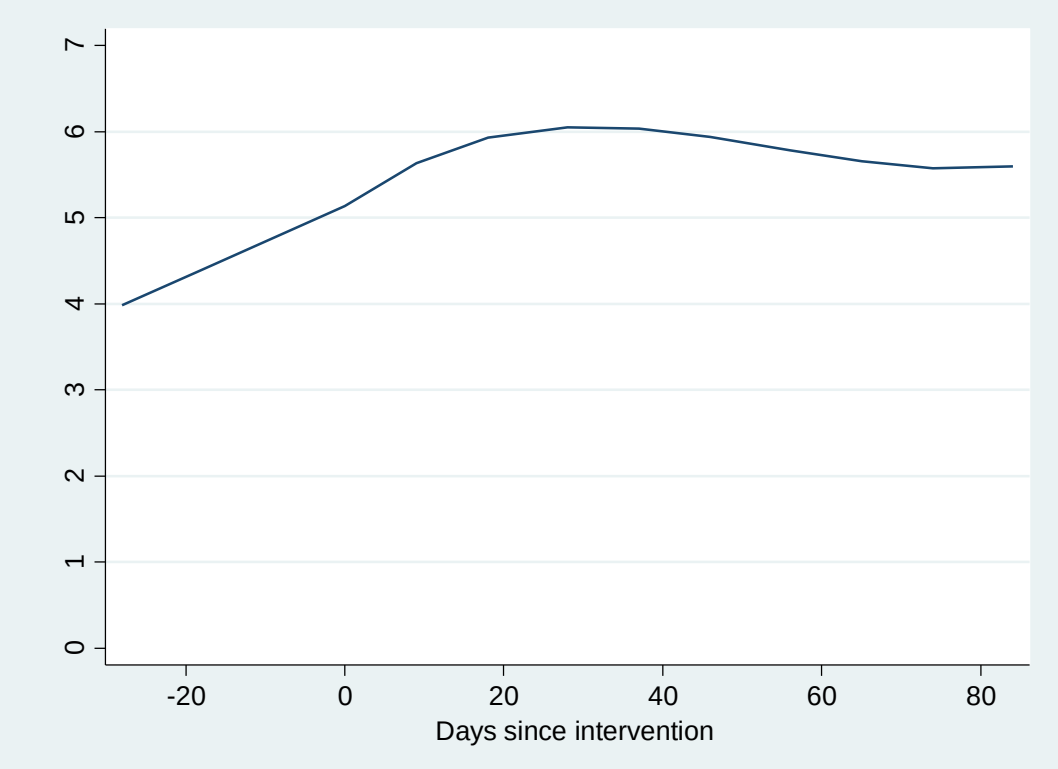

Figure 9 Graph of predicted flossing context stability
The graph depicts a participant assuming a baseline flossing rate of 4 times per month

Preliminary analysis to assess variables for inclusion in SEM

The other potential covariates were each investigated for inclusion in the investigation of the dynamic process of habit formation using SEM. Each covariate was treated as an outcome in a longitudinal regression, using predictors of group, age, sex, and baseline rates of that variable and other related variables. A backwards elimination procedure was employed, and it was noted whether time remained in the model, indicating that the variable changes over time. In order for a variable to be considered in the SEM analysis, it either had to have a baseline rate which predicted automaticity, or vary over time (as if a variable did not predict automaticity at baseline, and did not change over time, then it would not be possible for later measurements of the variable to impact upon automaticity). The covariates are considered according to these criteria in Table 13.

Variable	Baseline predictor in final automaticity model	Main effect for change over time? Nature of curve, and overall significance (Wald test, p)	Interaction between time and other variables? (Wald test p value for interaction terms with time)	Keep for SEM analysis
Subjective norm	No	No	-	No
Descriptive norm	Yes (p=0.007)	Yes - linear time (p=0.228)	interaction with Placement (p=.012)	Yes
Attractiveness motivation	No	Yes – quadratic time (p=.904)	interaction with Placement (p=.001)	Yes
Experiential attitude	No	Yes – linear time (p=0.001)	-	Yes
Hassle	No	No	-	No
Punishment	No	No	-	No
Reward	Yes (p<.001)	Yes – cubic time (p=.009)	interaction with Placement (p=.004)	Yes
Health motivation ¥	No	No	-	No
Perceived Behavioural Control ¥	No	No	-	No
Instrumental attitude ¥	No	No	-	No
Intention ¥	No	Yes – linear time (p<.001)	interaction with baseline intention (p=.003)	Yes
Attractiveness outcome evaluation ¥	No	Yes – linear time (p=.002)	interaction with Placement (p=.002)	Yes
Health outcome evaluation ¥	No	Yes – linear time (p=.969)	interaction with Placement (p=.014)	Yes

Table 13 Summary of the effect of each flossing covariate
¥ indicates that the variable is ordinal
The table presents the justification of whether or not each variable should be included as a potential covariate in the SEM analysis. In order to be included, the variables must either; have a baseline measurement which predicts automaticity; change over time (this can either be assessed by a significant main effect of time, or a significant interaction term with time).
The column for main effect of change over time reflects whether time remained in the model predicting the motivation variable. Some regressions contain a non-significant main effect of time, if there was a significant interaction effect with time. Any significant interaction effects are shown in the following column. The interaction effects tested with time were Placement, Focus, and the baseline measurement of the outcome variable.

Test of effectiveness of the Attraction and Health interventions on attractiveness and health motivations

The backwards stepwise regression models for the outcomes of health belief and attractiveness motivation are presented in Table 14 and Table 15. This is to further test whether the Attraction and Health interventions had the desired corresponding effects on motivation. Attractiveness motivation was included in the model predicting health motivation, and vice versa, in case the tendency to hold one type of motivation is negatively related to the tendency to hold the other type of motivation.

		Regression of health motivation (ordinal)			
Predictor		**B**	**SE**	**p**	**Wald test, p**
Intercept, high health motivation		0.189	0.474	0.691	
Intercept medium health motivation		6.009	0.735	<.001	
Baseline flossing frequency		0.157	0.071	0.028	
Baseline health outcome evaluation					<.001
	Low	-0.515	1.154	0.656	
	Medium	-2.440	0.638	<.001	
	High	0	.		

Table 14 Test of Focus intervention effect on health motivation
Random intercepts model of the ordinal variable of health motivation.

Time did not remain in the model for the categorical variable of health motivation (Table 14), which implies that this variable did not change significantly over time. The probability of having higher health motivation for flossing at the end of the study, increased with increasing baseline flossing frequency (b=0.157, p=.028). Those with high baseline scores for health outcome evaluation (i.e. those who feel that having good dental health is very important) had the highest health motivation scores at the end of the study. Interestingly, the final health motivation scores were not significantly different between those with high and low outcome evaluation scores, but those with medium baseline outcome evaluation scores had the lowest health motivation scores. As the Focus assignment did not remain in the model, this suggests that the Health versus Attraction interventions did not differentially affect the beliefs participants held about the health benefits of flossing.

Predictor		Regression of attractiveness motivation			
		B	SE	p	Wald test, p
Intercept		3.066	0.330	<.001	
Time group					0.904
	Adj time	-0.006	0.005	0.284	
	Adj time squared	-01.1~	0.59~	0.055	
Placement	**After TB**	-0.590	0.228	0.011	
	Before TB	0	.	.	
Baseline attractiveness motivation		0.516	0.057	<.001	
Health outcome evaluation					0.004
	Low	0.596	0.259	0.023	
	Medium	-0.322	0.165	0.052	
	High	0	.	.	
Timegroup and Placement interaction					<.001
	Adj time x After TB	0.008	0.007	0.268	
	Adj time x Before TB	0	.	.	
	Adj time squared x After TB	1.90~	0.82~	0.021	
	Adj time squared x Before TB	0	.	.	

Table 15 Test of Focus intervention effect on attractiveness motivation
Random slopes model of attractiveness motivation. Cubic time was removed from the model as it was not significant.
~ Values multiplied by 10,000, as quadratic effects have very small parameter estimates.

From Table 15 it can be seen that contrary to expectations, there was not an effect of intervention Focus on the attractiveness motivation. There was also no effect of attractiveness outcome evaluation. Those in the After TB group showed lower final attractiveness scores compared with those in the Before TB group (b=-0.590, p=.011). Higher baseline attractiveness motivation is associated with higher final scores (b=0.516, p<.001). There is a significant interaction between Placement and time (p=.001). These different patterns in attractiveness scores between the placement groups, yet no difference between the Health and Attraction groups was unexpected. This suggests that the Focus intervention did not differentially affect whether participants felt that flossing would make them more attractive.

As neither the Attraction nor Health interventions had the desired effect on the attractiveness motivation or health belief respectively, this may be one reason why the Focus intervention was not observed to be a significant predictor of behaviour or automaticity, as the interventions did not work as intended.

Effect of perceived relative effectiveness of flossing

At T4 (the final timepoint), participants were asked whether they thought flossing had any benefit over and above brushing (with responses on a five-point Likert scale). This variable of "perceived relative effectiveness" was found to correlate with behaviour (r=0.259, p=.005), and with automaticity (r=0.341 p=.0002). It is interesting to see that the correlation is stronger with automaticity than behaviour, which is consistent with what would be expected if assigning greater value to a behaviour means that it is reinforcing and thus leads to stronger habits. As this variable is seen to be associated with automaticity, it will also be investigated using the SEM analysis.

3.4.5 Hypothesis assessment

There was no difference observed between flossing behaviour or automaticity of participants randomised to floss before or after brushing, suggesting that Placement in a routine does not have an impact upon automaticity.

The Focus assignment to interventions based on Attraction or Health did not have the desired effect on attractiveness and health motivations. However, there was also no evidence of an effect of either attractiveness or health motivations on behaviour or automaticity. Therefore, the hypothesis is not supported that interventions based on attraction will lead to greater automaticity than those based on health.

3.4.6 Structural Equation Modelling of habit formation

Selection of covariates for SEM

The covariates which were found to vary over time above were investigated for their effect on automaticity using Structural Equation Modelling (SEM). These were: attractiveness motivation, experiential attitude, descriptive norm, reward, intention, attractiveness outcome evaluation, health outcome evaluation, and context stability. Age was also included here as it was found to be a significant predictor of both automaticity and behaviour in the longitudinal regressions. The effect of conditions (Placement and Focus) was not included in the SEM, as they were found in the regression analysis not to predict either behaviour or automaticity.

Separate models were fitted to predict automaticity at each timepoint (T1-T4). The variable of "wave" was added as a predictor of current behaviour, to allow for better estimation using maximum likelihood with missing values, due to changes to the process following the first wave of participants.

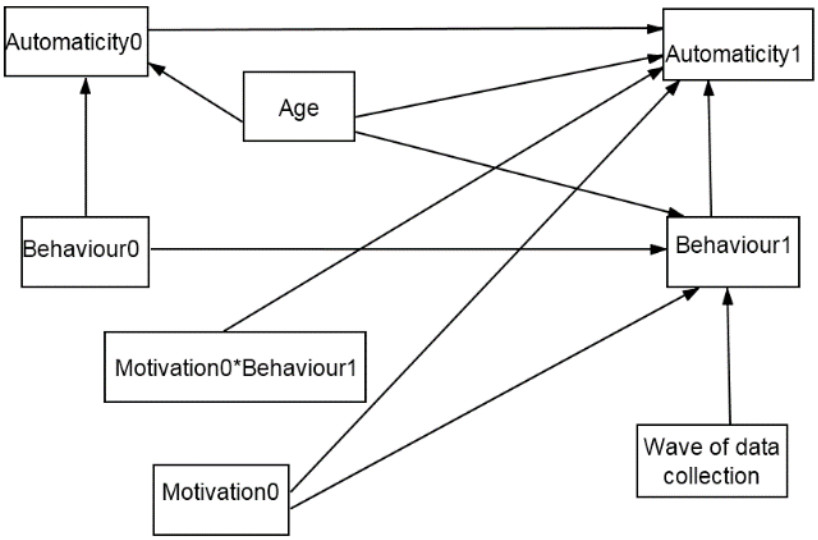

Figure 10 Example of simple model predicting automaticity at T1
Each different motivation variable was tested individually in this model.

From their inclusion individually in a simple model (as in Figure 10, above, which shows the model predicting automaticity at T1), it was determined whether each motivation variable had an impact on behaviour or automaticity directly or whether they moderated the behaviour-automaticity relationship. This screening model was repeated for the predictors of automaticity for the rest of the four timepoints. At T4, this testing was also done with the variable of whether flossing would thought to have benefit over and above brushing – perceived relative effectiveness (as this was only measured in the final questionnaire). Variables were retained for later analysis if at least one of the relationships listed above were significant in at least one of the four (timepoint-specific) models. The variables retained were: experiential attitude, reward, attractiveness outcome evaluation, descriptive norm, intention and context stability. The fact that attractiveness motivation was not a significant predictor of behaviour (ps>.065) or automaticity (ps>.255), in any of the models, suggests that contrary to hypothesis 2, attractiveness was not found to be an effective motivator for behaviour change, or an effective way to achieve habit formation.

Following this initial screening of covariates, the models were further developed to include one motivation variable at a time with the full set of direct and indirect effects on automaticity (mediation via behaviour, and moderation using the inclusion of the motivation behaviour interaction), but to also control for the direct effects on automaticity and behaviour of all other significant motivations from the simple models. Descriptive norm and attractiveness outcome evaluation were included as predictors of behaviour only, as they had no significant pathways to automaticity in the simple models. In order to reduce the number of variables tested, the reward and experiential attitude items were combined, as they are conceptually related, and the variables were found to be strongly correlated r=0.82, p<.001. The combined items gave a score with Cronbach's alpha=0.92. The combined variable is referred to as "rewarding experience". The coefficients and significance levels of the pathways of all potential covariates at both these levels of screening are shown in Appendix 9. An example of the model when testing the covariate of intention is shown in Figure 11. All variables with significant pathways to behaviour or automaticity in the second screening model (controlling for effects of the other covariates), were retained to comprise a full conceptual model.

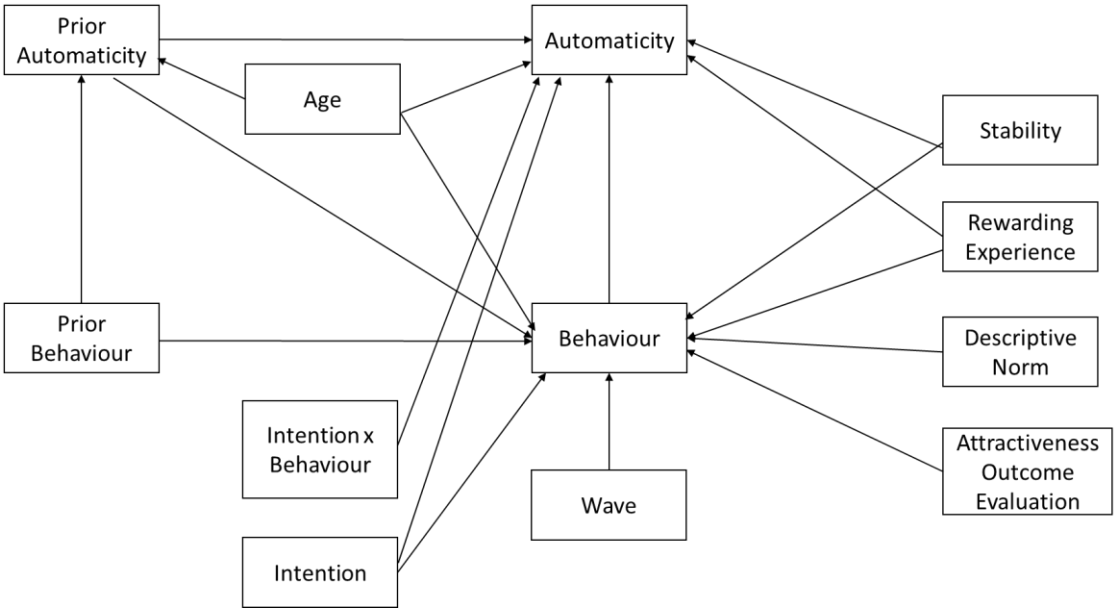

Figure 11 Example of the second stage SEM screening model
Each variable found to be significant from the first round screening model was tested in a single model, and one variable at a time was tested with all three paths to automaticity (direct, mediated via behaviour, and moderating the behaviour-automaticity relationship).

The variables which are retained for the full model are rewarding experience, intention, and context stability. An example of the full conceptual model is shown in Figure 12. As this model now only contains the covariates which appeared to have an impact upon automaticity (and also behaviour), further expected pathways which were included. One was between past automaticity and future behaviour. Another pathway was added between experienced reward and intention as it would be expected that intention would mediate the effect of reward on behaviour (Ajzen, 1991). These changes were observed to improve the goodness of fit of the model, as measured by the Comparative Fit Index (CFI). Age was only included as a predictor of automaticity and current behaviour as it was not seen to be predictive of any other variables in the model in the regression analyses, or to predict context stability in the regression models.

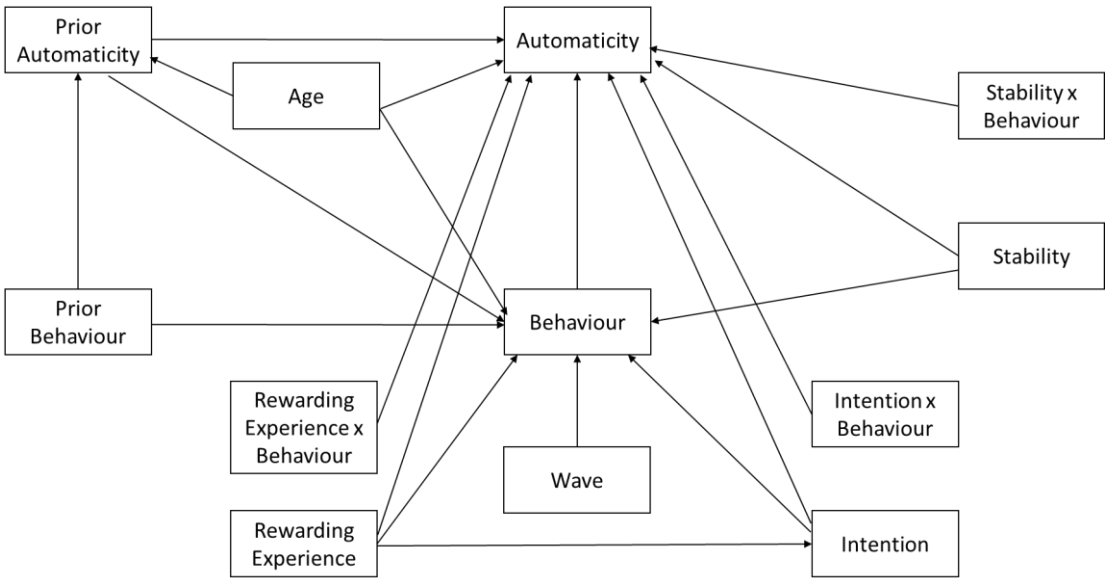

Figure 12 Full conceptual SEM model for flossing automaticity
This was tested at each timepoint (version A and B vary according to whether the covariates of rewarding experience and intention are measured at the same timepoint, or at the previous timepoint compared to the outcome).

A further improvement to the model fit was achieved through changing the measurement selected for the reward and intention variables. Originally, rewarding experience and intention at the previous timepoint was used to predict behaviour and automaticity at the next timepoint (behaviour was measured as self-reported frequency in the past week). This was version A. However, intention was not a significant predictor of behaviour in these models. This is counter to theoretical and empirical expectations that intention should at least be

weakly predictive of behaviour (Ajzen, 1991; Webb & Sheeran, 2006), but may not be surprising, as it is advised that intention be measured as close as possible to the point of the behaviour (Randall & Wolff, 1994). As rewarding experience and intention may change over the course of the four week interval (Loehr et al., 2013; Sheeran & Abraham, 2003), the model was reformulated so that the measures of intention and rewarding experience concurrent with the behaviour and automaticity measurement were used as predictors (version B). The outputs are presented for both version A (in Table 17) and version B (in Table 18). Given the lack of any significant effect of intention on behaviour in model A, the model with contemporaneous measures of the covariates (model B) will be considered in depth instead. In order to illustrate the predictive ability of this model, simple regressions were constructed given the pathways to behaviour and automaticity for both model A and model B at each timepoint. The R squared values for these models is presented in Table 16.

Figures are shown below illustrating the significant pathways of this model using contemporaneous time, for each timepoint. This fit of model B appears to be slightly greater than model A, and after T1, the model appears to explain close to three quarters of the variance in observed automaticity.

	T1, R^2	**T2, R^2**	**T3, R^2**	**T4, R^2**
Models with covariates at time X-1: Version A				
Automaticity	0.539	0.521	0.707	0.711
Behaviour	0.477	0.414	0.718	0.686
Models with covariates at time X: Version B				
Automaticity	0.536	0.679	0.744	0.703
Behaviour	0.500	0.544	0.752	0.683

Table 16 R squared values for the simple regressions obtained from each SEM model.
This indicates how well each model explains the variance in the data for the main outcomes of automaticity and behaviour.

SEM Version A	T1, N=118		T2, N=118		T3, N=118		T4, N=118	
	Coeff	p	Coeff	p	Coeff	p	Coeff	p
Hypothesised predictors of automaticity								
Past automaticity	0.383*	<.001	0.072	.383	0.432*	<.001	0.564*	<.001
Behaviour	0.414*	.045	0.282*	<.001	0.291*	<.001	0.188*	.002
Intention	0.368*	.010	0.104	.632	0.201	.204	-0.202	.195
Intention * Behaviour Interaction	-0.068	.349	-.017	.748	0.108*	.006	0.062	.101
Rewarding Experience	-.431*	.026	0.440	.070	-0.120	.546	0.301	.126
Rewarding Experience * Behaviour Interaction	0.010	.915	-0.006	.897	0.131*	.002	-0.021	.579
Stability	0.208*	.003	.073	.646	0.060	.555	0.110	.315
Stability * Behaviour Interaction	0.009	.872	0.016	.724	-0.038	.286	-.043	.152
Age	-0.003	.799	0.032*	.003	-.002	.844	0.006	.574
Hypothesised predictors of behaviour								
Past behaviour	0.102*	.018	0.307*	.020	0.686*	<.001	0.680*	<.001
Past automaticity	-0.082	.504	-0.335*	.015	0.002	.986	0.001	.990
Intention	0.035	.779	0.175	.397	0.047	.723	0.113	.466
Rewarding Experience	-0.150	.436	0.575*	.003	0.170	.256	0.151	.343
Stability	0.368*	<.001	0.450*	.001	0.201*	.037	0.073	.536
Age	0.002	.882	0.044*	.010	-0.006	.649	0.043*	.003
Wave	-.735*	.005	0.039	.897	0.007	.970	0.405	.068
Hypothesised predictors of past automaticity								
Past behaviour	0.127*	<.001	0.454*	<.001	0.447*	<.001	0.514*	<.001
Age	0.026*	.026	0.009	.479	0.029*	.014	0.015	.229
Hypothesised predictor of intention								
Rewarding Experience	0.305*	.001	0.429*	<.001	0.596*	<.001	0.602*	<.001
CFI	.336		.725		.709		.697	

Table 17 Flossing SEM results (Version A).
Past behaviour and past automaticity refers to behaviour and automaticity measured at the previous timepoint.
The model fit was assessed using the Comparative Fit Index (CFI), where values approaching 1 indicate better fit
This model uses covariates measured at the timepoint prior to the behaviour and automaticity timepoint.
*Significant variables are marked with a **

SEM Version B	T1, N=118		T2, N=118		T3, N=118		T4, N=118	
	Coeff	p	Coeff	p	Coeff	p	Coeff	p
Hypothesised predictors of automaticity								
Past automaticity	0.294*	.002	0.091	.188	0.399*	<.001	0.513*	<.001
Behaviour	0.171	.181	0.181*	.010	0.259*	<.001	0.179*	.002
Intention	0.030	.827	0.127	.367	0.188	.171	-0.229	.239
Intention * Behaviour Interaction	-0.048	.543	-0.045	.306	-.082*	.023	0.073	.079
Rewarding Experience	0.227	.148	0.488*	.015	-.011	.952	0.447*	.026
Rewarding Experience * Behaviour Interaction	-0.003	.970	0.040	.349	0.120*	.002	-0.034	.390
Stability	0.230*	.001	0.185	.109	0.061	.555	0.120	.238
Stability * Behaviour Interaction	-0.015	.798	-0.025	.503	-0.034	.348	-0.046	.110
Age	-.002	.867	0.037*	<.001	0.001	.926	0.004	.685
Hypothesised predictors of Behaviour								
Past behaviour	0.079	.060	0.300*	.010	.641*	<.001	0.657*	<.001
Past automaticity	-0.113	.363	-0.271*	.024	0.004	.975	0.047	.694
Intention	-0.176	.261	0.446*	.008	0.305*	.013	0.224	.181
Rewarding Experience	0.343*	.017	0.459*	.008	0.144	.238	0.004	.979
Stability	0.298*	<.001	0.437*	<.001	0.133	.157	0.068	.561
Age	0.007	.605	0.054*	<.001	0.001	.951	0.042*	.003
Wave	-0.634*	.016	-0.035	.902	0.013	.941	0.409	.072
Hypothesised predictors of past automaticity								
Past behaviour	0.127*	<.001	0.458*	<.001	0.447*	<.001	0.513*	<.001
Age	0.026*	.026	0.010	.429	0.032*	.007	0.016	.201
Hypothesised predictor of intention								
Rewarding Experience	-0.113	.363	0.595*	<.001	0.560*	<.001	0.649*	<.001
CFI	.605		.759		.738		.669	

Table 18 Flossing SEM results (Version B)
This model uses covariates measured at the timepoint prior to the behaviour and automaticity timepoint.

Testing full conceptual model of automaticity gain

Model for automaticity at T1

As illustrated in Figure 13, the model B predicting automaticity at T1 (the intervention timepoint) showed that automaticity is predicted by its value at baseline (b=0.294, p=.002). Behaviour in the week preceding the intervention was not predicted by behaviour at T0 (baseline) (b=0.079, p=.060). T0 automaticity was predicted by T0 behaviour (b=0.127, p<.001) and also by age (b=0.026, p=.026). At T1, higher context stability predicted higher levels of behaviour (b=0.298, p<.001) and automaticity (b=0.230, p=.001). Rewarding experience significantly predicted behaviour (b=0.343, p=.017), but not intention (b=-0.113, p=.363). Intention had no impact upon behaviour (b=-0.176, p=.261) or automaticity (b=0.030, p=.827). This is not unexpected, as the intention is measured following the intervention, whereas the automaticity and behaviour questions were asked about the behaviour prior to the intervention.

Considering model A, as presented in Table 17 (with rewarding experience and intention measured at T0, the month prior to the automaticity and behaviour outcomes), intention was found to significantly predict automaticity (b=0.368, p=.010) but not behaviour (b=0.035, p=.779). Rewarding experience was also a significant predictor of intention at this point (b=0.305, p=.001).

Model for automaticity at T2

This model is shown in Figure 14. By T2, there was no longer a significant relationship between automaticity at T1 (the intervention timepoint) and T2 (b=0.091, p=.188). This was likely due to the effect of the intervention. However there was still an impact of behaviour at T1 on behaviour at T2 (b=0.300, p=.010). Interestingly, while there was a relationship from automaticity at T1 to behaviour at T2 (b=-0.271, p=.024), it was negative, suggesting that those with higher automaticity at the point of the intervention showed lower behaviour four weeks later. This is the opposite of what would be expected. Increasing age was predictive of higher behaviour (b=0.054, p<.001) and automaticity (b=0.037, p<.001). Behaviour had a significant effect on automaticity (b=0.181, p=.010). This suggests that the effect of age on automaticity was both direct, and mediated by increased levels of behaviour. Context stability was still

predictive of flossing behaviour (b=0.437, p<.001). There was a significant direct effect of rewarding experience on automaticity (b=0.488, p=.015), and one mediated by behaviour (pathway from reward to behaviour, b=0.459, p=.008). Intention also mediated the effect of rewarding experience on behaviour (pathway from intention to behaviour, b=0.446, p=.008).

Model for automaticity at T3

By T3 (shown in Figure 15), automaticity was predicted by current behaviour (b=0.259, p<.001) and past automaticity (b=0.399, p<.001), and behaviour was predicted by past behaviour (b=0.641, p<.001). Age was no longer directly predictive of behaviour (b=0.001, p=.951) or automaticity (b=0.001, p=.926), but there was an indirect effect on automaticity at T3 through automaticity at T2 (pathway from age to T2 automaticity: b=0.032, p=.007). Stability no longer predicted behaviour (b=0.133, p=.157). Rewarding experience only had an effect on behaviour mediated by intention (pathway from rewarding experience to intention, b=0.560, p<.001, pathway from intention to behaviour, b=0.305, p=.013). At T3 there were two significant moderation effects seen of the behaviour-automaticity relationship, one by rewarding experience (b=0.120, p=.002) and a negative moderation effect from intention (b=-0.082, p=.023). These relationships were illustrated by plotting simple slopes, as shown below[12]. With higher scores for rewarding experience (Figure 17), the relationship between behaviour and automaticity was stronger, suggesting that rewarding experience reinforces behaviour such that more rewarding behaviour repetitions lead to greater gains in automaticity. The pattern is reversed for intention (Figure 18), whereby those with stronger intentions had a weaker relationship between behaviour and automaticity. This implies that, people performing a behaviour more intentionally, were less likely to be doing it automatically. It may reflect that those who have strong intentions to perform a behaviour were likely to be doing it through planned rather than automatic processes.

Model for automaticity at T4

By T4, the patterns have changed again (Figure 16). Automaticity was predicted by behaviour (b=0.179, p=.002), and both automaticity (b=0.513, p<.001) and behaviour (0.657, p<.001) were predicted by their respective scores at T3. Age had a direct impact on behaviour

[12] It is important to note that for the observed moderation pathway to represent a real moderated effect, the assumptions must be met of having the correct model specification, no measurement error, and no unmeasured confounding.

(b=0.042, p=.003). There were no longer any effects of stability or intention, on behaviour or automaticity. Rewarding experience had a direct impact upon automaticity only (b=0.447, p=.026) – there is no longer the moderation effect observed in the third month for either rewarding experience (b=-0.034, p=.390) or intention (b=0.073, p=.079).

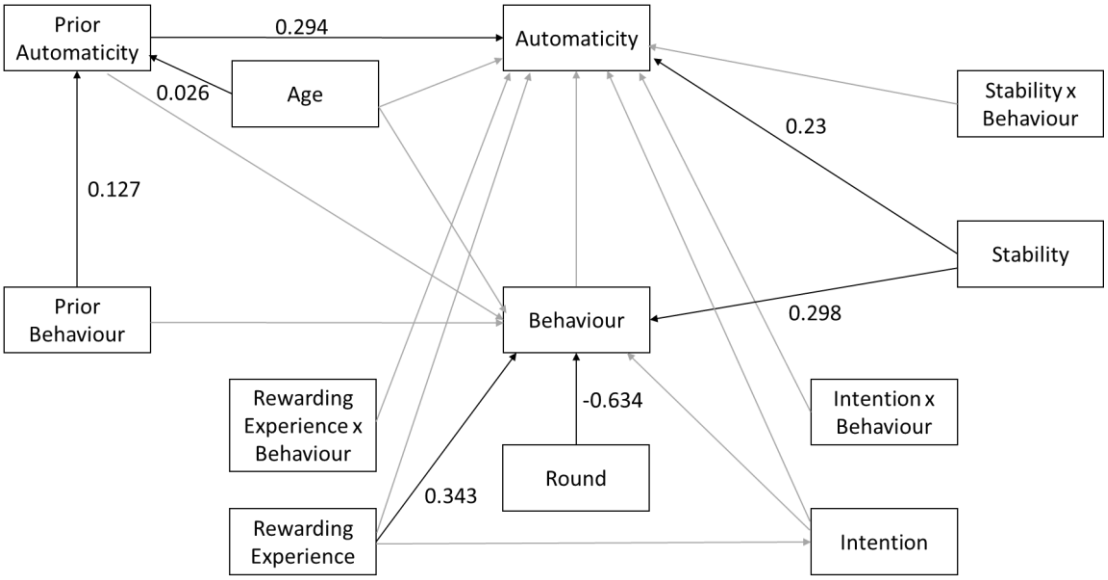

Figure 13 SEM model B predicting flossing automaticity at T1
Grey arrows correspond to non-significant relationships.

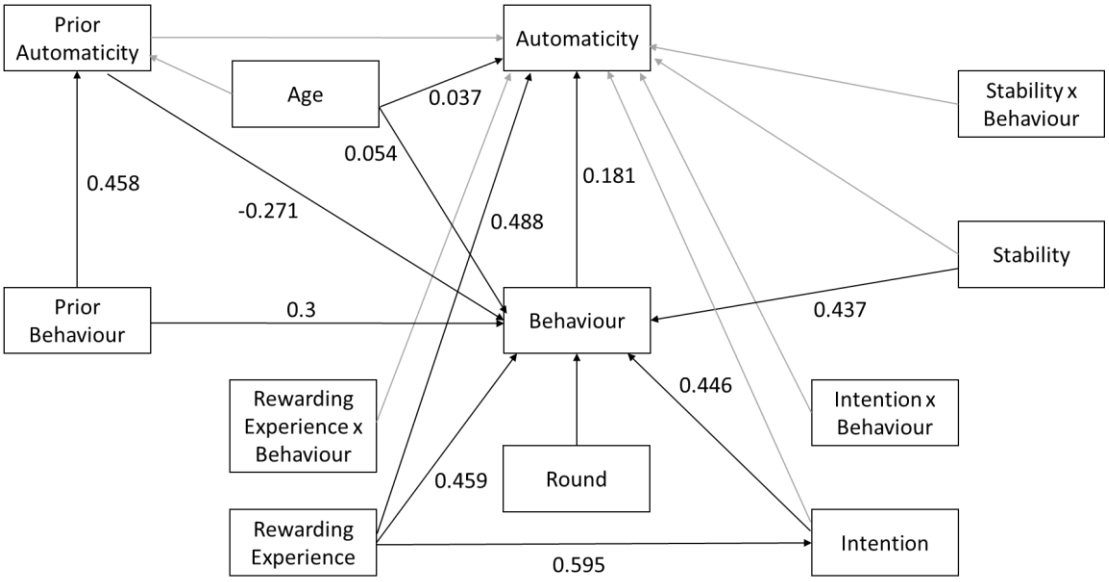

Figure 14 SEM model B predicting flossing automaticity at T2

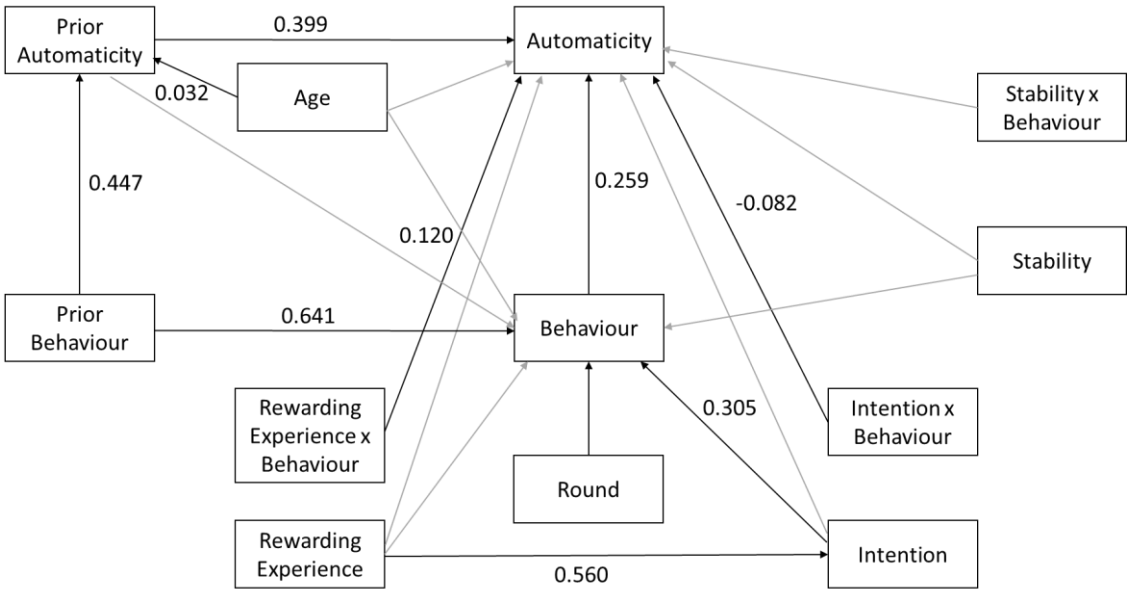

Figure 15 SEM model B predicting flossing automaticity at T3

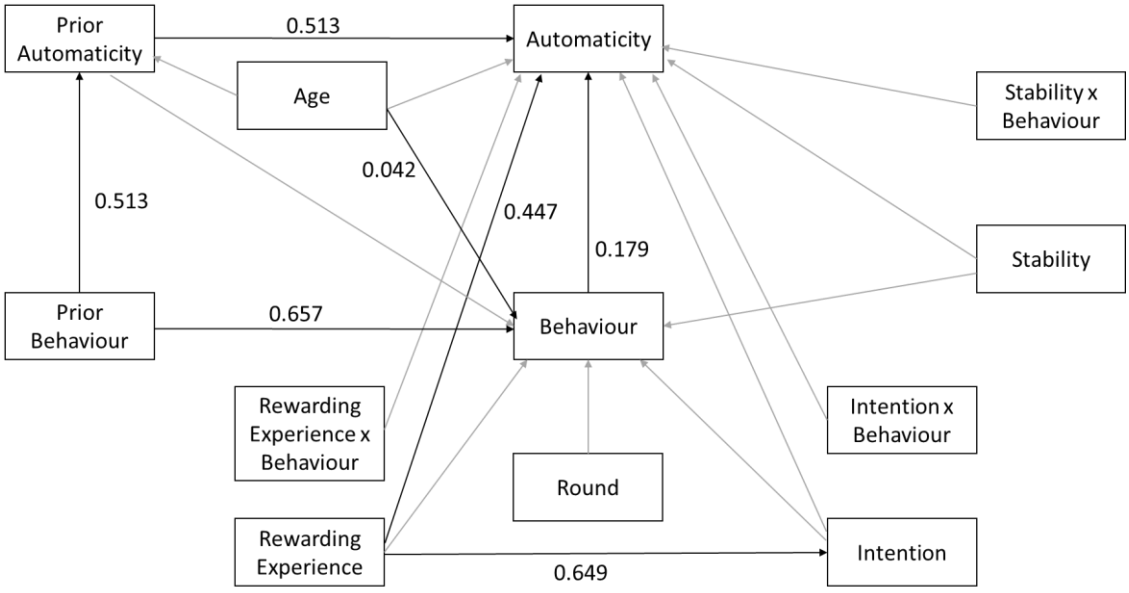

Figure 16 SEM model B predicting flossing automaticity at T4

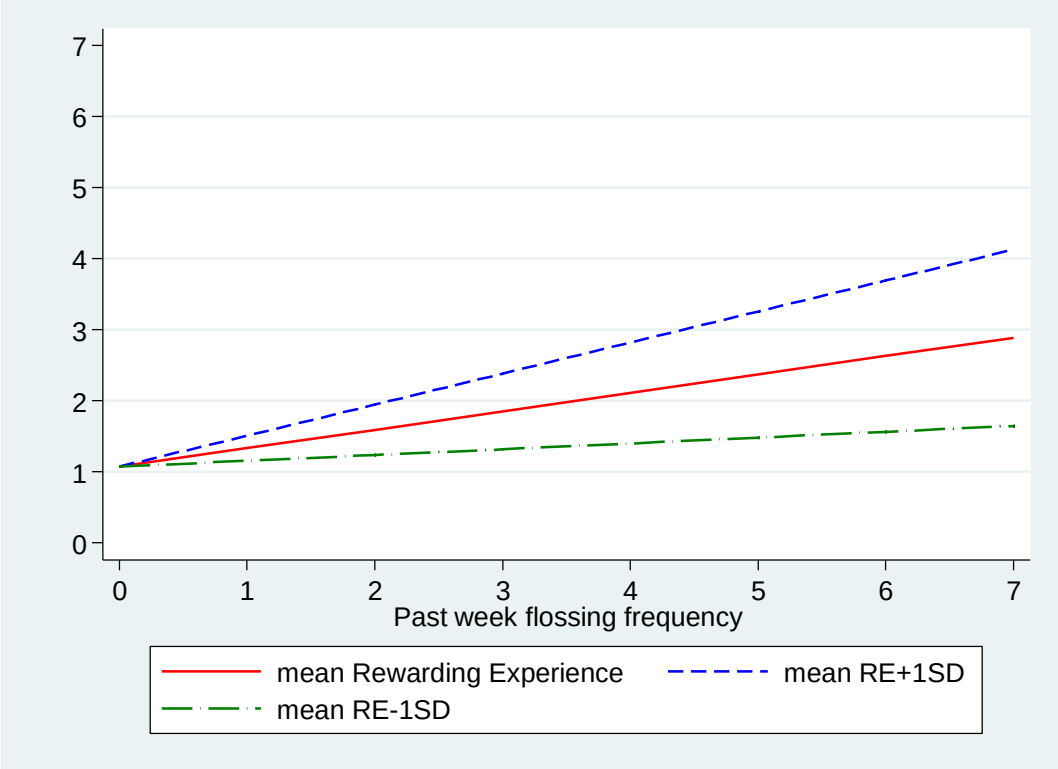

Figure 17 Effect of behaviour on flossing automaticity, moderated by rewarding experience

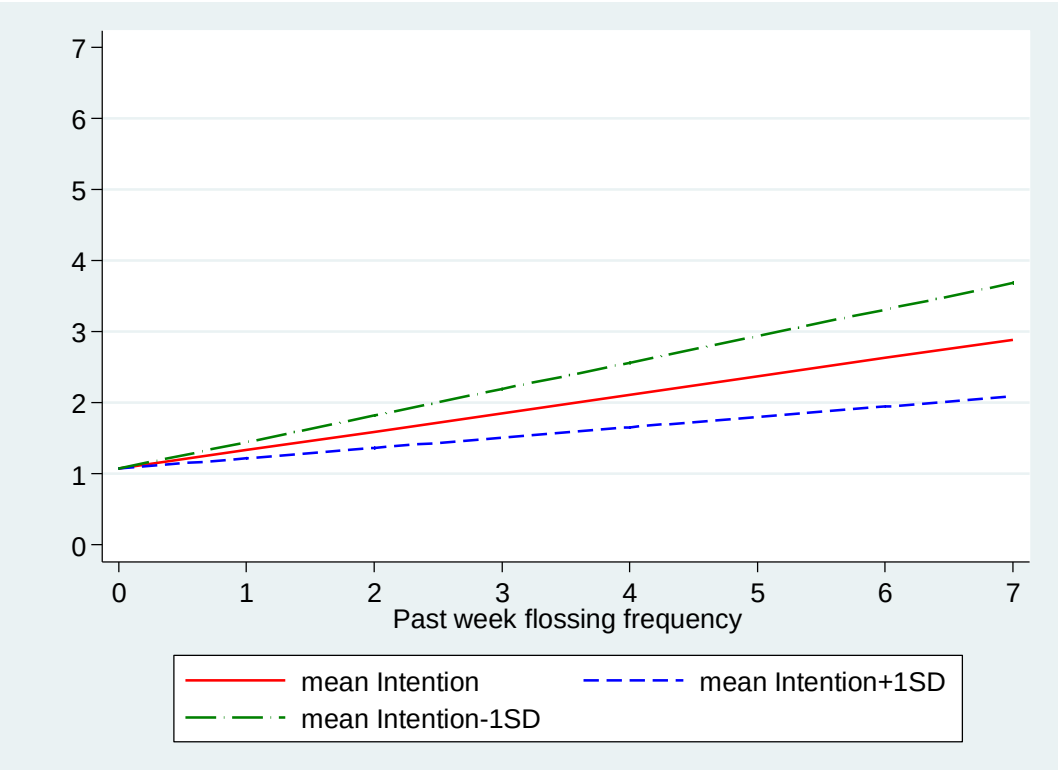

Figure 18 Effect of behaviour on flossing automaticity, moderated by intention

Hypothesis assessment

It was expected that rewards will moderate the behaviour-automaticity relationship, by leading to greater increases in automaticity for each behaviour repetition. There is some support for this hypothesis, as it was observed at T3, but not at any other timepoint.

A direct effect of reward on autoamticity was observed aty T2 and T4. While this was not the theoretically expected moderated effect, it further suggests that the role of reward is not completely mediated by behaviour.

3.5 Discussion

3.5.1 Summary

The results from the flossing data show that the intervention conditions of Placement (Before or After brushing) and the Focus of the intervention (Attraction or Health) did not have the expected effects on behaviour or automaticity. However, there was a significant effect of reward, whereby both a direct impact of reward on automaticity was observed, as well as reward moderating the effect of behaviour on automaticity. Interestingly, the observed rates of behaviour over the course of the study were not predicted by the prior behavioural frequency of the participant. This suggests the flossing intervention was effective at changing behaviour regardless of baseline rates. It is interesting to note that participation in the study alone leads to increases in behaviour and automaticity, even before the intervention session.

3.5.2 Effect of Attraction versus Health intervention

The hypothesis was that interventions based on attraction (which is a basic human motivation, and potentially rewarding) would be more effective at promoting behaviour repetition and automaticity than interventions focussed on plans to improve health.

To investigate this, the effectiveness of the interventions in prompting changes in the related motivations was tested. Simple comparisons - looking at increases in the attractiveness and health motivation scores over time and comparing these changes by group - revealed that the groups did not differ in the changes in their attractiveness scores. This suggests that the Attraction intervention did not actually have the desired effect of making participants feel

more strongly that flossing their teeth would make them more attractive. The health motivation scores did show greater increases for the Health group compared to the Attraction group for about a month following the intervention, however these differences did not persist. This shows that the health based intervention did have a stronger effect on beliefs about Health than the Attraction intervention, but only for a limited time.

The outcomes are slightly different when considering the complex longitudinal regressions. Considering first the attractiveness motivation, there was no effect of condition, suggesting that the Attraction and Health groups did not differ on this outcome, which is consistent with the simple analysis. There was no effect of group at all for the health motivation, so perhaps the limited difference at the start of the study could not be detected when looking at trends over the entire study. This was despite including in the regressions, variables measuring the value ascribed to having good dental health or an attractive smile. This suggests that the Attraction intervention did not work as intended to modify the attractiveness motivation, and the Health intervention had at best a small and temporary effect on beliefs about health.

The two interventions conditions were set up with leaflets based on the two different types of motivation (Aunger & Curtis, 2013). As this was a simple intervention, delivered at one timepoint only, it may not be surprising that the two interventions did not have significantly different effects on motivation. While the intervention did successfully change behaviour, the simple presentation may not have been distinct enough to cause significantly different changes to motivation. Other studies testing different motivations often compare their effects to a control condition, rather than making comparisons between different types of intervention groups, such as a study comparing simple text-based interventions testing different motivations for their effectiveness in changing handwashing with soap (Judah et al., 2009). However, it has been observed from an investigation of an intervention promoting physical activity, that there was a poor match between intervention components delivered by a facilitator, and perceived by participants (Michie et al., 2008). Therefore, it may be the case that the components differentiating the two intervention types were not strongly internalised by the participants.

As the study was powered for a medium effect size, it is possible that there was not enough power to detect significant group differences. However, even a trend to the Attraction group having higher behaviour or automaticity scores to the Health group was not observed. Furthermore, it would be expected that any differential effect of the Focus interventions on behaviour would be mediated by changes in the relevant motivation (Lally & Gardner, 2013). Therefore, the failure of the intervention to have effects on their target motivations means that the interventions would not be expected to have differential effects on the main

outcomes of behaviour or automaticity. Consistent with this expectation, the Focus intervention groups did not differ in their rates of self-reported flossing behaviour. Likewise, there were no group differences on automaticity. While participants did show increases in behaviour and automaticity, the Focus-specific aspects of the interventions may have simply been too weak to result in group differences either in motivation, or the outcomes of behaviour or automaticity. For this reason, while it is possible that an effect was not detected due to a lack of power, this is not likely.

However, despite the interventions not having the desired effects, it should still have been possible to test the underlying assumption of the hypothesis - that attractiveness motivations have a greater effect on behaviour and automaticity than health motivations. Again, this was observed not to be the case. The baseline scores of neither of these variables were observed to impact upon behaviour or automaticity throughout the study. The health motivation did not show significant changes over time, so later scores can also be assumed to have no impact upon behaviour or automaticity. The attractiveness scores did change over time. As changes over time were observed, the attractiveness motivation was investigated using the SEM analysis, for its effect on automaticity at each timepoint. However, when included individually in the simple model, the attractiveness motivation did not have a significant direct effect, indirect effect (through behaviour) or moderation effect at any point throughout the study.

The hypothesis that attractiveness motivations are more effective than health interventions at leading to behaviour change and habit formation is not supported by the data, both in terms of interventions designed to test this strategy, and in terms of the proposed relative effectiveness of the underlying motivations.

In order to understand this finding, it may be useful to consider the two motivations independently. For the Health motivation, while the increases seen between baseline and T1 and T2 were significant, they were small (Cohen, 1992). In the longitudinal analysis, there were no significant differences in health motivation over time from the point of the intervention onwards. Without this change over time, or with an impact of the baseline rate on later automaticity, it cannot be said to have an impact on automaticity. This variable was transformed into a categorical variable for the analysis, as it was skewed. This meant that most participants had high health motivation scores. As there was very little variability in responding across participants, and little change over time, it is perhaps not surprising that this factor does not predict automaticity gain.

The Attraction intervention did not have the desired effect of promoting attractiveness motivation to a greater extent than for the group who received the Health intervention. This

perhaps seems strange, as the Attraction intervention contained more messages that may have been unexpected by participants than the health intervention, as the latter may have had more in common with the information commonly given by dental health professionals (Duley et al., 2012; Hedman, Ringberg, & Gabre, 2009; McConaughy, Lukken, & Toevs, 1991). Therefore it would have been plausible to find greater differences in the Attraction than the Health group. This was the opposite of what was found. However, it may have been the case that participants found the focus on attractiveness strange in this context, and perhaps less believable or reliable (Choo et al., 2001).

Attraction is a theme often used in marketing and advertising in order to change behaviour and sell products (Baker & Churchill Jr, 1977; Colarelli & Dettmann, 2003). There is evidence from a developing country context, that attraction is a more effective motivator for handwashing with soap than health messaging (Aunger et al., 2010; Curtis et al., 2009). However, it is not known whether this relative effect of attraction and health generalises across behaviours and populations. A study of motivations for dental health behaviour in adolescents found that those who smoked, brushed less frequently or were more socially disadvantaged, were more likely to brush for cosmetic (i.e. attraction) rather than health reasons (Macgregor, Balding, & Regis, 1997). These predictors of the preference of different types of motivational drivers of behaviour suggests that the notion that a single type of motivation will be most effective at promoting behaviour change across the population may be overly simplistic. Instead, dental health interventions may be more successful if they are congruent with participants own drivers for change (Sherman, Mann, & Updegraff, 2006).

3.5.3 Effectiveness of Placement: flossing Before or After brushing

The other main hypothesis in this chapter was that behaviour change and habit formation for flossing after brushing would be more effective than for flossing before brushing. This is not supported by the data. There was no difference between the groups in either a simple comparison of change in behaviour rates from the point of the intervention to the end of the study, or in the full longitudinal regression of predictors of behaviour. The longitudinal analysis of automaticity showed no effect of Placement in a routine. The simple comparison of change in automaticity scores revealed an opposite result to what was expected, with the Before brushing group showing greater increases than those in the After brushing group. This finding, in contradiction with the expectation of the hypothesis, suggests that the lack of a positive effect is not likely to be due to a lack of power in this instance.

The hypothesis that flossing after brushing should be more likely to lead to automaticity than flossing before brushing was derived from an earlier study, and Event Segmentation Theory (Zacks et al., 2007). The original flossing study testing this effect showed marginally significant group differences four weeks following the intervention, and significant group differences at eight month follow up (Judah et al., 2012). However, this was a small-scale and short-term study, with only 50 participants for the main study, and 29 who responded after eight months. The main purpose of the current study was to confirm these exploratory findings with a longer and more robust study. However those initial findings were not supported here.

The theoretical basis for this hypothesis was Event Segmentation Theory. This hypothesis was a novel prediction derived from the theory and not a necessary part of the theory. The theory is based on evidence of how people chunk observed sequences of behaviour, and concerns memory and brain processing across "event boundaries", which mark the interface between actions comprising sequences of related activities. As memory is disrupted across event boundaries (Speer & Zacks, 2005; Swallow et al., 2009), it was expected that cues may become less effective if the implementation intention reminder occurs before or at an event boundary, and the target behaviour occurs after an event boundary (as may be more likely to be the case with flossing before, as opposed to after brushing). The disrupted memory trace may make behaviour more difficult to be performed even if the cue does not occur prior to the event boundary. Furthermore, as there is increased brain processing at the event boundary as opposed to within an event (Ruh et al., 2005), it was expected that behaviours occurring at this point (i.e. at the beginning of an event) may be less likely to be handed to automatic control and become habitual than behaviours occurring at the middle or end of an event. These expectations of increased behavioural frequency or increased automaticity gain were not observed.

The assumption inherent in this hypothesis is that the same processes are in place when processing one's own behaviour as when observing the behaviour of another person. Given literature on the differences in comprehension of own versus another's behaviour, this assumption may not hold (Jones & Nisbett, 1971; Malle, Knobe, & Nelson, 2007), so the generalisation of Event Segmentation Theory to the process of behaviour change and habit formation may not be valid. Even if this is a plausible comparison, as idiosyncratic routines differ, it may be the case that participants do not have a specific dental care event, but that brushing is part of a larger "getting ready for bed" event. If this were the case, then the assignment to the Before brushing group would not necessarily mean that participants were adding flossing at an event boundary any more than the After flossing group. Therefore, the assignment to the Before brushing and After brushing groups may have not been a sufficient

test of the hypothesis. However if this is the case, it is not clear how the hypothesis could be tested in other situations, as if brushing teeth cannot be classified as a dental care event then it is not clear what routines this hypothesis could be relevant to.

Alternatively, it is possible that the literature on routine behaviour may lead to expectations contrary to this hypothesis. This has been proposed in key work describing promotion of habit formation (Lally & Gardner, 2013). While it was assumed in the present study that the increased brain processing at event boundaries would lead to decreased probability of forming new habits, it has also been observed that action slips are more likely to occur at this point (Botvinick & Bylsma, 2005), which is believed to be due to weaker connections at this point with the next action. At event boundaries, there are many actions that might next be performed, resulting in less competition from an established habit (Lally & Gardner, 2013). Therefore, event boundaries, or task completion points, are proposed to be an effective point to attempt insertion of a new behaviour. It is plausible then, that different principles may be conflicting in their effects on the ease of adding a new behaviour at an event boundary: advantages from less competition from an established habit, and disadvantages from a cue being less effective due to memory disruption and more potential behaviour variation. These competing processes may result in no overall advantage for one point in a routine as opposed to another. The initial study investigating this was limited, and found only tentative results (Judah et al., 2012). Therefore, the present study suggests that there is no differential effect between adding a new behaviour at an event boundary or within an event, in particular with regards to flossing before or after brushing.

3.5.4 Effect of rewarding experience

As anticipated, there was a significant effect of reward on automaticity. This variable was combined with experiential attitude for the SEM analysis as they are conceptually similar, and highly correlated. Different pathways between reward and automaticity support different empirical or theoretical claims in the literature. Typically, habits have been thought to form primarily through behavioural repetition, and so rewarding experiences would promote habit formation through increasing the likelihood of the behaviour being repeated (Triandis, 1977; Wood & Neal, 2007; Wood & Neal, 2009). A finding of an indirect effect of reward only – one that is fully mediated by the impact of behaviour on automaticity - would have supported this theory. The behaviourist literature, and models of habit formation in animals would support the expectation that reward moderates the behaviour-automaticity relationship, such that

behaviour repetitions that are more rewarding, reinforce the behaviour, and therefore lead to greater gains in automaticity (de Wit & Dickinson, 2009; Dickinson, 1985). This moderation relationship would be demonstrated by a significant interaction term between rewarding experience and behaviour, and has been observed in a study of fruit consumption habits (Wiedemann et al., 2014). The third approach is the theoretically unexpected one that reward has a direct impact on automaticity. This has been empirically observed in a small habit formation study (Judah et al., 2012) and a study of existing physical activity habits (Gardner & Lally, 2013), however it does not have known theoretical justification. The findings were attributed to a small sample size not allowing the more complex moderation effect to be observed in the former study (Judah et al., 2012), and the limits of the cross sectional design in the latter (Gardner & Lally, 2013). This study allowed the effect to be investigated with a more robust study design.

The pathways that were observed to be significant between reward and automaticity varied across the SEM models at different timepoints. One theory that can be ruled out by the data is the idea that reward has an impact on automaticity gain solely mediated by the effect of reward on behaviour.

Reward had no impact at the point of the intervention. Four weeks later, reward had both a direct impact on behaviour and automaticity. The direct effect between reward and behaviour at this point is expected, as if people find a new behaviour to be rewarding they are more likely to do it more. However, it is not clear why there is also a direct effect of reward on automaticity at this point rather than an effect moderating the behaviour-automaticity relationship. This direct effect of reward on behaviour is not observed again. This is perhaps not surprising, as following this point, behaviour is strongly predicted by behaviour in the previous month. Eight weeks after the intervention, reward only works through moderating the effect of behaviour on automaticity. By twelve weeks, reward again has a direct impact on automaticity, but no direct effect on behaviour. The interpretation of these findings relies on the assumptions that the model is correct, there is no measurement error, and no unmeasured confounding. Assuming these assumptions hold, the findings support the theoretically expected moderation effect, and also the unexpected direct effect on automaticity. It is not immediately clear why the effect of reward on automaticity changes over time, and then changes back again. Yet the findings support the idea that finding something to be rewarding has a greater impact on automaticity than one just mediated by behaviour repetition.

3.5.5 Effect of context-dependent repetition

Another key tenet of current habit theory is that habits form through "context-dependent repetition" (Lally & Gardner, 2013; Lally et al., 2010). Context stability was measured here by combining scores for how often people floss their teeth at the same point in their routine every time, and in the same place every time. This measurement was retained to the final SEM analysis. It may have been expected that if repetition in a constant context is to aid habit formation, then it too would moderate the behaviour-automaticity relationship. However this was not observed to be the case. The only significant pathway observed from context stability was to behaviour (there was no direct effect on automaticity, or moderation of the behaviour-automaticity relationship), suggesting that context-dependent repetition purely aids habit formation through making it more likely that the behaviour will be performed.

This direct effect on context stability on behaviour was observed at the point of the intervention, suggesting that those who flossed prior to the intervention were more likely to do it in the same context each time. This effect persisted four weeks later, however it declined in magnitude by eight weeks following the intervention, and was no longer present at twelve weeks. From this it may be deduced that performing a behaviour in a stable context (place, and point in the routine) has an impact when initiating a new behaviour, however has less of an impact over time once habits are formed. This claim is surprising though, as context change is known to be a key way to disrupt established habits (van't Riet et al., 2011; Verplanken et al., 2008), so it would be expected that this would remain a significant predictor. However, these studies refer to larger changes in performance context, such as changing location or modifying the environment, than would have been observed here. The measure of context stability used was only a very limited one of place and point in the routine. Therefore, this may not have been an adequate test of context-dependent repetition, which could be expected to relate to other situational factors (Verplanken, 2005; Wood & Neal, 2007).

3.5.6 Effect of age

Age was also a significant predictor of behaviour and automaticity at certain points in the study. This may be partially because there is evidence of conscientiousness increasing with age (Jackson et al., 2009; Srivastava, John, Gosling, & Potter, 2003; Terracciano, McCrae, Brant, & Costa Jr, 2005), which may result in people being more likely to act upon a commitment they have made. This finding also suggests that, contrary to the saying (you can't teach an old dog

new tricks), older people may be more likely to form new habits. The effect of age on behaviour or automaticity did not appear to be mediated by older people having greater levels of context stability.

3.5.7 Effect of intentions

Differences were seen between the models constructed including the intention measure from the same timepoint as behaviour and automaticity, or intention measured one month prior to behaviour and automaticity. With the measurement one month prior, intention was not seen to be a predictor of behaviour at any timepoint. This is consistent with findings that intentions are less predictive of behaviour in the long-term than in the short-term (Randall & Wolff, 1994; Paschal Sheeran, 2002; Verplanken, 2006). Due to the expectation that intentions should at least somewhat predict behaviour (Webb & Sheeran, 2006), the models with intentions and rewards measured at the same timepoint as behaviour and automaticity were considered in depth. (There was less discrepancy between significant pathways from reward between the two models than there was for intention, suggesting that finding something rewarding has a longer-lasting impact that having strong intentions.)

The model with contemporaneous measures of intention, behaviour and automaticity, saw a significant pathway from intention to behaviour four and eight weeks following the intervention. At eight weeks, both model formulations (with contemporaneous and non-contemporaneous measures of intention and behaviour), showed that strong intentions weaken the relationship between behaviour and automaticity. This suggests that people still performing the behaviour intentionally are less likely to have high scores for automaticity than those who are not performing the behaviour intentionally. This is consistent with the fact that by eight weeks following the intervention, for those who have formed habits, automaticity is assumed to have increased which then compensates for the natural decline in intention over time (Tobias, 2009). However, this weakening of the behaviour-automaticity relationship contrasts with the findings of another flossing habit formation study, which observed that strong intentions result in implementation intentions leading to a greater gain in flossing automaticity over four weeks, compared with weak intentions (Orbell & Verplanken, 2010). Yet the SEM analysis meant that the present study could also control for the effect of behaviour, therefore it can be seen that intentions have an effect on automaticity which is mediated by behaviour. The potential discrepancy between these two studies can be resolved as strong intentions led to more frequent behaviour (which promotes automaticity gain), but

strong intentions may also result in each behavioural repetition having less of an impact on automaticity. In addition, the present study observed an association between reward and intention scores, whereas it was the reward scores that were found to strengthen automaticity gain, as opposed to intentions. The present analysis is better placed to separate these multiple potential predictors of behaviour and automaticity.

The lack of an observed effect for outcome evaluations (whether having good dental health, or having attractive teeth is felt to be important,) on behaviour or automaticity suggests that goals in this sense are not important in the development of habits. This is further evidence against the view of habits as automatic goal-directed action (Aarts & Dijksterhuis, 2000; Aarts et al., 1997).

3.5.8 Conclusions

There is no evidence in support of the hypothesis that flossing after brushing is more likely to lead to automaticity than flossing before brushing. There is also no support for the hypothesis that interventions based on attractiveness are more likely to lead to greater automaticity than interventions based on health. Nor is there any evidence that either attractiveness motivation, or health belief is effective at predicting behaviour or automaticity. There is some evidence to support the hypothesis that reward moderates the relationship between behaviour repetitions and automaticity gain, and the assertion is well supported that the impact of reward on automaticity is not solely mediated by behaviour repetition. These findings about reward are an important contribution to the study of human habit formation in the real world.

Chapter 4: Results – Effects of reward on vitamin habit formation

Table of Contents

4.1 Introduction

The background to the study is presented in more detail in the Introduction and Methods chapters, but is summarised again here. Participants who participated in the second and third waves of data collection received the intervention for vitamin C. Taking vitamin C tablets is a suitable target for habit formation studies, as it is a simple behaviour (Lally & Gardner, 2013; Maddux, 1997), which is performed once daily, and can be occur in a constant context (Lally et al., 2010).

The question under investigation here is whether perceived reward reinforces behaviour, thus promoting automaticity gain, and if so, what factors count as rewards in this context. Only

intrinsic types of reward were considered. It is expected that finding something to be rewarding will lead to sustained practice of that behaviour (Rothman, 2000). However, of greater interest, is whether rewards strengthen the link between behaviour and automaticity gain. This is a theoretical expectation from the animal learning and neuroscience literature, which holds that reward will strengthen the connection between a stimulus and response, resulting in habit formation (Dickinson, 1985). This would be demonstrated by reward moderating the behaviour-automaticity relationship, with greater levels of reward leading to a greater impact of behaviour repetition on automaticity. This has been observed in past habit studies (Gardner & Lally, 2013; Wiedemann et al., 2014), however, these studies only considered existing habits, so it is not yet clear whether this prediction correctly describes the human habit formation process.

Reward here will be defined as a reinforcer of behaviour which leads to automaticity gain. Different potential factors which may function as reward will be investigated, including variables related to pleasure, intrinsic motivation and the attitudes regarding the value of the outcomes of the behaviour. The different potential reward types were measured by self-report. It is expected that acting in accordance with these features may be experienced as being rewarding, and therefore reinforce behaviour.

Pleasure is expected to act as a reward due to the parallels with the hedonic rewards such as sucrose solution, used in animal studies of habit formation (Broadbent, Squire, & Clark, 2007; Faure, Haberland, Conde, & El Massioui, 2005). Attitudes and beliefs are tested due to the positive association between attitude and automaticity observed in a study of the formation of a flossing habit (Judah et al., 2012). The assertion was made that for human habit formation, acting in accordance with positive outcome expectancies may reinforce behaviour. There is also empirical support for intrinsic motivation moderating the behaviour-automaticity relationship (Gardner & Lally, 2013; Wiedemann et al., 2014) and directly predicting automaticity (Gardner & Lally, 2013) in studies of existing habits.

The results presented in this chapter address whether perceived reward reinforces behaviour, thus promoting automaticity gain, and if so, what factors count as rewards in this context.

The hypotheses tested in the current chapter are:

H3: Reward will moderate the behaviour-automaticity gain relationship, by leading to greater increases in automaticity for each behaviour repetition.

H4: Different psychological features will serve as rewards to reinforce behaviour. These are:

a. **Reward as pleasure.**
b. **Reward as positive attitude (both global attitudes, and specific beliefs about outcomes).**
c. **Reward as intrinsic motivation (as opposed to extrinsic motivation).**

4.2 Methods

The study procedure was outlined in Table 1 in the Methods chapter. As part of the online questionnaire completed at baseline (T0), participants were given an online intervention (see Appendix 2), with information about the benefits of vitamin C and potential benefits of vitamin C supplementation. They were asked to try to take a vitamin C tablet once a day, and to think about when and where they would take their tablet. Participants were provided with a bottle of vitamin C tablets. The information that was presented at T0 was reiterated four weeks later, as part of the questionnaire at T1, to serve as a booster to behaviour in case levels had started to fall. This was in the form of multiple choice questions about the benefits of vitamin C, followed by the answers along with some further explanation. The intervention is described in more detail in the Methods chapter, in line with the TIDieR intervention description checklist (Hoffmann et al., 2014), and the Behaviour Change Technique Taxonomy (v1) (Michie et al., 2013).

The different psychological factors investigated as potential rewards were measured in the questionnaires sent every four weeks during the study, along with self-report measures of behavioural frequency, context stability and automaticity, using the Self Report Behavioural Automaticity Index (SRBAI). The potential rewarding variables tested were: reported pleasure of performing the activity, positive global attitude (whether the behaviour is held to be generally useful or not), positive beliefs or outcome expectancies (believing in certain specific benefits of the behaviour), and being intrinsically motivated to perform the behaviour. A variable for general reward was also included. The questionnaire items are described within the Methods chapter (Table 3).

4.3 Analysis

4.3.1 Overview

The analysis for this study is summarised here. The results of the preliminary analyses are presented in the current section where they concern the treatment of the variables for the main analysis. This includes whether covariates are analysed as continuous or categorical variables, and the combination of some of the reward variables into a single variable.

Longitudinal regression analyses of the main outcomes (behaviour, automaticity, as well as context stability) will be described. These regressions investigate any baseline predictors of these main outcomes, as well as allowing visualisation of their trajectories of these outcomes over the course of the study. The hypotheses were addressed using Structural Equation Modelling, to test the effect that each potentially rewarding variable had on automaticity, using a separate model for each timepoint.

4.3.2 Preliminary analysis

Initial checks of the data

Variables that had a negatively skewed distribution were turned into ordinal variables by splitting them into three categories. The continuous covariates are: context stability, pleasure, general reward, vitamin belief, and intrinsic, integrated, identified, and external motivation, and amotivation (the six relative autonomy subscales). The ordinal covariates are: intention and perceived behavioural control.

Correlations between covariates and treatment of variables

Correlations between the six relative autonomy subscales were investigated to see if they had the expected patterns. Correlations between all other reward variables and covariates are also presented, to see whether they were associated with one another. The magnitude of strong correlations were identified (Cohen, 1992).

As shown in Table 19, the majority of the motivation and reward items were significantly correlated. Automaticity correlates strongly with behaviour, context stability and intention. Behaviour only shows a medium correlation with intention, but does show a strong correlation with context stability. Of the reward items, automaticity correlates strongly with the relative autotomy subscales on the intrinsic side of the spectrum (intrinsic, integrated and identified), as well as pleasure and general reward. Behaviour does not correlate strongly with any of the reward items.

The amotivation item showed negative correlations with the other positive reward and motivation items. The strongest relationships were observed between general reward, pleasure and intrinsic motivation, and also between identified motivation and vitamin belief and intention. PBC did not show strong correlations with any other reward or relative autonomy variables.

The general reward and pleasure items were combined into a single construct, termed "pleasure", (Cronbach's alpha=0.888), as they were highly correlated and overlapped conceptually. The variables for global attitude, and vitamin belief were retained in their current form.

When considering the correlations observed for the relative autonomy subscales, the expected positive correlations were seen between intrinsic, integrated, and identified motivations (which are all on the intrinsic side of the relative autonomy spectrum). However, while it was expected that external regulation should correlate negatively with identified and intrinsic motivation, a positive correlation was observed here. Additionally, positive correlations are expected between amotivation, and external and introjected regulation. However, these correlations were very small and not significant.

Due to these unexpected patterns between subscales, the overall relative autonomy score (Markland & Ingledew, 2007; Markland & Tobin, 2004) (calculated using the weighted average of all subscales) was not used. Instead, the weighted average was calculated of the three intrinsic subscales only. As in the standard combination for the full relative autonomy score, this was calculated by giving the items measuring intrinsic motivation a weight of +3, the integrated items a weight of +2, and the identified items a weight of +1. Cronbach's alpha for this combined score was 0.906.

Descriptive statistics for behaviour and automaticity

Descriptive statistics were calculated and graphically depicted to visualise the changes in frequency of taking vitamin C tablets, and automaticity over the course of the study.

	1#	2#	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Behaviour#	1														
2. Automaticity#	**.669*** **	1													
3. Intrinsic	.341**	**.635*** **	1												
4. Integrated	.343**	**.563*** **	**.710*** **	1											
5. Identified	.339**	**.570*** **	**.700*** **	**.751*** **	1										
6. Introjected	.202	.377***	.427***	**.616*** **	.456***	1									
7. External	.066	.116	.296***	.446***	.300***	**.667*** **	1								
8. Amotivation	-.066	-.259*	-.352***	-.371***	**-.602*** **	-.038	.023	1							
9. Context stability	**.635*** **	**.720*** **	.311***	.345***	.323***	.241***	.125*	-.118*	1						
10. Global attitude	.232*	.427***	**.554*** **	**.548*** **	**.735*** **	.294***	.213***	**-.644*** **	.218***	1					
11. Pleasure	.344**	**.621*** **	**.801*** **	**.577*** **	**.588*** **	.329***	.209***	-.328***	.287***	**.537*** **	1				
12. General reward	.313**	**.584*** **	**.746*** **	**.630*** **	**.692*** **	.378***	.301***	-.461***	.229***	**.701*** **	**.782*** **	1			
13. Vitamin belief	.150	.334**	.460***	**.530*** **	**.617*** **	.463***	.320***	-.352***	.113	**.543*** **	.390***	**.517*** **	1		
14. Intention[ɣ]	.386***	**.568*** **	.375*	.204	.477**	.092	-.113	**-.485	.128	.482**	**.549** **	**.570** **	.369*	1	
15. PBC[ɣ]	.234*	.204	.337	.212	.320	.119	.010	*-.389	-.097	.463**	.440*	.476*	.227	**.608*** **	1

Table 19 Pairwise correlations between all vitamin C motivation and reward variables.
All correlations greater than 0.5 are seen as large correlations, and marked in bold (Cohen, 1992).
 # Correlations with behaviour and automaticity are conducted at T4 only.
[ɣ] indicates that intention and PBC are ordinal variables, and therefore all correlations with these variables are with Spearman's rho.
** p<.05, ** p<.01, *** p<.001*

4.3.3 Regression of baseline predictors of behaviour, automaticity and context stability

As in the flossing chapter, preliminary analyses of the main variables were conducted using longitudinal mixed effects models, which allow for both fixed and random effects. This was in order to control for repeated measures of the outcome within participants and households, over time. Linear, quadratic, and cubic effects of time were included in the model, to allow flexibility in the predicted relationship over time. Baseline measures of all potential reward variables and other motivational covariates were included in the initial models. A backwards elimination procedure was employed using the Wald test, in order to refine the models by removing variables that do not contribute significantly, until a final model was reached. (The vitamin belief items were measured at timepoints T0, T1 and T4. If this variable were to be included as a predictor of automaticity or behaviour in the regression model, then as the values for T2 and T3 would be missing, the participant would be excluded completely. Therefore this variable is only included in the subsequent Structural Equation Models, rather than the regressions.)

The predicted values from the final models were plotted in order to display the expected trajectory of these outcomes over the course of the study. As well as providing a way to visualise the predicted outcomes, this analysis also allowed identification of any baseline predictors of the main outcomes of automaticity and behaviour, as well as context stability.

4.3.4 Structural Equation Modelling

Structural Equation Modelling (SEM) was conducted to predict dynamic predictors of habit formation over the course of the study, in addition to the baseline predictors tested in the regression models. A full conceptual model was constructed to predict automaticity, with separate models constructed for each timepoint in the study (due to constraints of sample size). The predictors included current and past behaviour, and past automaticity, along with reward. The conceptual model was tested with one type of potentially rewarding variable at a time (pleasure, global attitude, specific beliefs, intrinsic motivation), to compare the impact of each type of reward on habit formation in turn. As different variables are being tested for their rewarding nature, it was appropriate to test each separately using individual models.

Three different pathways were included from the rewarding variable in the model. These paths were: an effect on automaticity mediated by behaviour; a moderation effect modelled

by an interaction term between reward and behaviour; a direct effect on automaticity. (The interaction term was deterministically defined as the product of the two interacting variables.) While the direct effect from potentially rewarding features to automaticity is not theoretically supported, it has been observed in previous studies of existing habits (Gardner & Lally, 2013), and habit formation (Judah et al., 2012), therefore this pathway was also tested here. Separate cross-sectional models were constructed for each of the four timepoints following the intervention period. The predictors used were those measured at the same time as the behaviour and automaticity outcomes (specification version B from Chapter 3).

Intention and context stability were also considered as covariates, with pathways to behaviour and automaticity. Interaction terms were also created between behaviour and each of intention and context stability, and these interaction terms were modelled with a pathway to automaticity. These variables were included so that the full conceptual model would be comparable to that tested in the flossing chapter, and as they are both theoretically expected to be important in the habit formation process. Intention is expected to have some impact upon behaviour (Webb & Sheeran, 2006), and including it may provide evidence on how the effects of intention on behaviour changes over the habit formation process. A path from the reward variable to intention was included. Context stability was included as an expected predictor of automaticity gain (Lally & Gardner, 2013; Lally et al., 2010). Age was initially included as a predictor of automaticity, as it was retained in the final regression model. However it did not significantly predict automaticity in any of the SEM models for any of the potential reward variables, or at any timepoint, therefore the variable of age was removed from the final conceptual model. The conceptual model is shown in Figure 19.

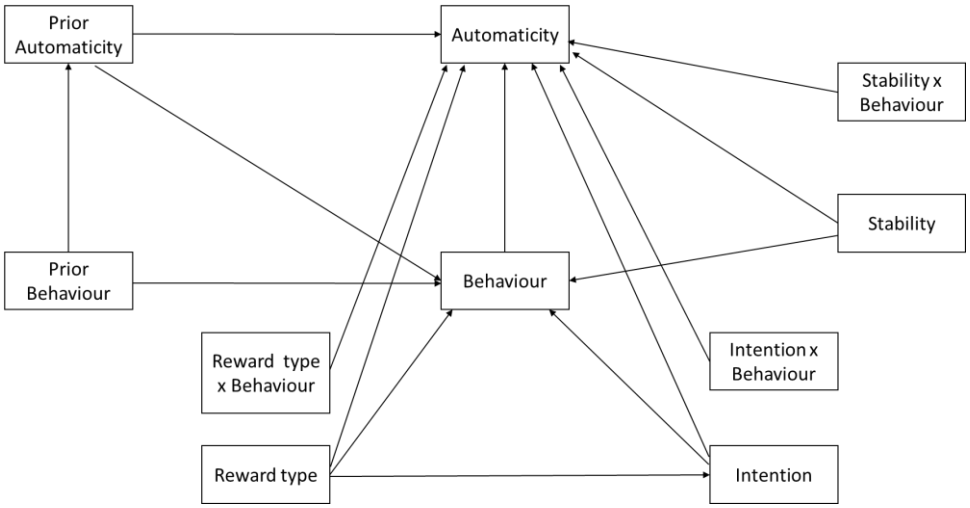

Figure 19 Full conceptual SEM model for vitamin C automaticity

Note: The term "Reward" here denotes each of the reward variables of pleasure, intrinsic motivation, general attitude and specific vitamin beliefs, which were tested in turn. The model was repeated for each of the timepoints T1-T4.

At T1, participants who said they never take vitamin C tablets at the start of the study had their vitamin automaticity score set to missing, due to the possibility that they had implicit or dormant habits if they had performed the behaviour regularly before. To avoid the exclusion of all incomplete records, Maximum Likelihood estimation was implemented via the EM algorithm (Rabe-Hesketh & Skrondal, 2006). For all other timepoints, there was no adjustment for missing values.

4.4 Results

4.4.1 Descriptive statistics

Eighty participants took part in the vitamin study. Participants had a mean age of 35.1 years (SD=11.8) and the sample included 45 women (56.3%). At T0 the mean vitamin C tablet adherence was very low. Fifty seven participants (72%) reported taking a vitamin C tablet zero times per month on average at T0. The remaining 23 participants who reported non-zero monthly frequency at T0, took vitamin C a mean of 4.86 times a month (SD=3.39). At T0, the mean automaticity scores were 2.11 (SD=1.25). However, this calculation excludes the 47 participants who reported automaticity scores of zero, indicating that they never do the behaviour (due to the possibility that they may have implicit habits if they used take vitamin tablets regularly). A sharp increase in automaticity and behaviour occurred at T1, which appears to be followed by a small decline in behaviour by T2 (Figure 20).

Simple t-tests indicated that increases were seen from T0 to T4 in behaviour ($t(77)=10.94$, $p<.001$), with mean weekly behaviour scores rising from 0.34 to 3.87. Increases were also seen in automaticity scores ($t(34)=5.30$, $p<.001$), with mean scores rising from 2.11 to 3.92.

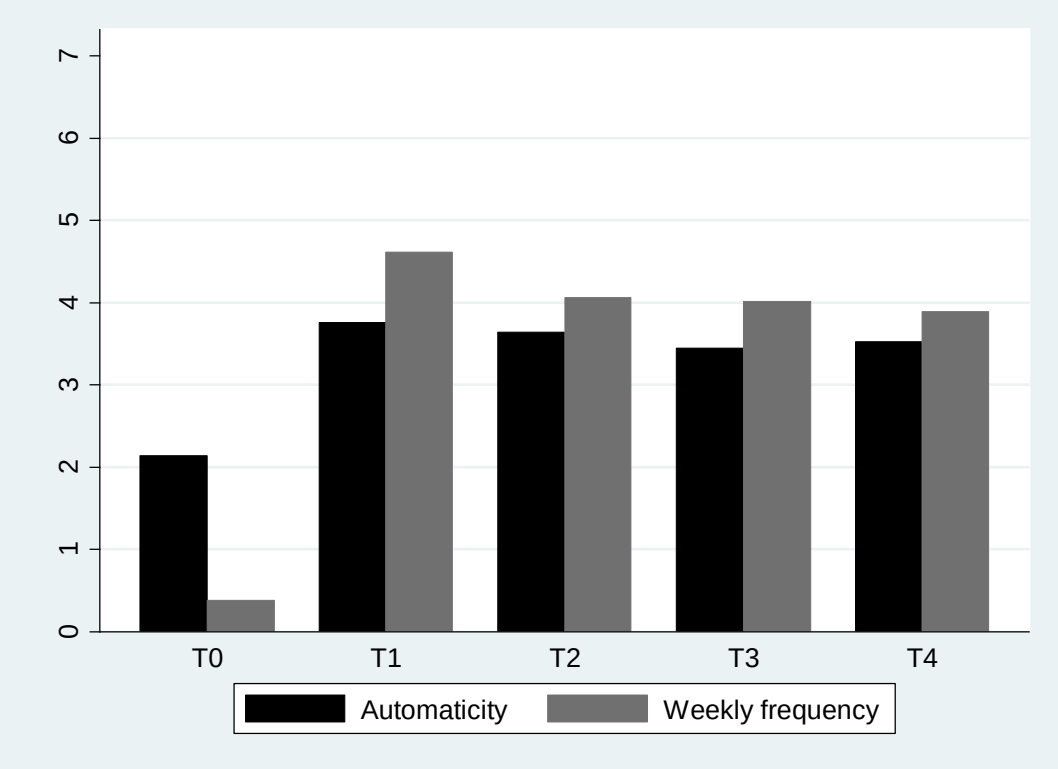

Figure 20 Mean vitamin C automaticity and behavioural frequency at each point in the study
The frequency at T0 was calculated by dividing by four the baseline score of the number of times participants reported taking a vitamin C tablet per month on average prior to the study. The subsequent behaviour score is the number of times participants report having taken a vitamin C tablet in the past week. As both outcomes of behaviour in the past week, and automaticity are measured on the same scale (0-7), they can be presented on the same graph with a single y axis.

4.4.2 Preliminary regression analyses

Regressions of baseline predictors of behaviour

The backwards stepwise regression predicting behavioural frequency excluded all variables apart from a linear effect of time (b=-0.008, p=.015). Therefore, none of the variables as measured at baseline were significant predictors of vitamin C behaviour over the course of the study.

Given the surprising finding that no variables apart from time predict vitamin C frequency, the sensitivity analysis was conducted by repeating the whole stepwise regression from the full model. This sensitivity analysis involved excluding four participants from the analysis[13]. There was no difference in the final model when these participants were excluded.

[13] Two participants indicated that they were aware that the study was about habit formation as they had searched for the researcher online. One participant took a multivitamin daily at the start of the study,

Regression of baseline predictors of automaticity

Predictor		Regression of vitamin C automaticity			
		B	**SE**	**p**	**Wald test, p**[14]
Intercept		-0.775	1.138	0.498	
Time group					<.001
	Adj time	0.024	0.009	0.008	
	Adj time squared	9.53~	2.15~	<.001	
	Adj time cubed	0.077~	0.014~	<.001	
Age		0.038	0.017	0.024	
Baseline pleasure		0.581	0.180	0.002	

Table 20 Final model of vitamin C automaticity
A random slopes model was used. Adjusted (Adj) time= time minus 112 days, so the end of the study is at the intercept, and the intervention occurs at -112 days.
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

The model for vitamin C automaticity is shown in Table 20. There was a significant effect of initial pleasure scores (b=0.580, p=.002) on automaticity scores over the study, suggesting that the extent to which participants feel taking vitamin C tablets is pleasurable at the beginning of the study, was associated with automaticity levels throughout the study. There was also a small effect of age (b=0.038, p=.024), whereby older people had higher automaticity scores.

The regression for automaticity shows a significant linear, quadratic and cubic effect of time. The trajectory of automaticity can be observed from Figure 21 of predicted values for a hypothetical participant. The figure shows that there was a steady increase in automaticity from the start of the study, which then slows and plateaus around 40 days following the intervention. There is then a gradual decline, however final automaticity levels are still higher than they were at baseline. Automaticity shows an increase of around two points over the

and so would be more familiar with the target behaviour than most. One participant was trying to get pregnant, and so was taking a multivitamin for this purpose which already contained vitamin C, and so answered all the questions about this supplement instead. As the motivation for this would be likely to be different than for taking vitamin C tablets, this participant was excluded in the sensitivity analysis.

[14] As the linear, quadratic and cubic effects of time are included in the model, and tested for their inclusion in combination using the Wald test, in these cases the Wald test is different from the p values of the final model. Therefore, for the test of the combination of time effects, and for the interaction terms, the Wald test is cited in the tables in order to indicate whether the parameter estimates for the individual variables should be interpreted as being important in the model.

course of the study. Graphical comparisons between the predicted and observed values of automaticity for each participant are shown in Appendix 10.

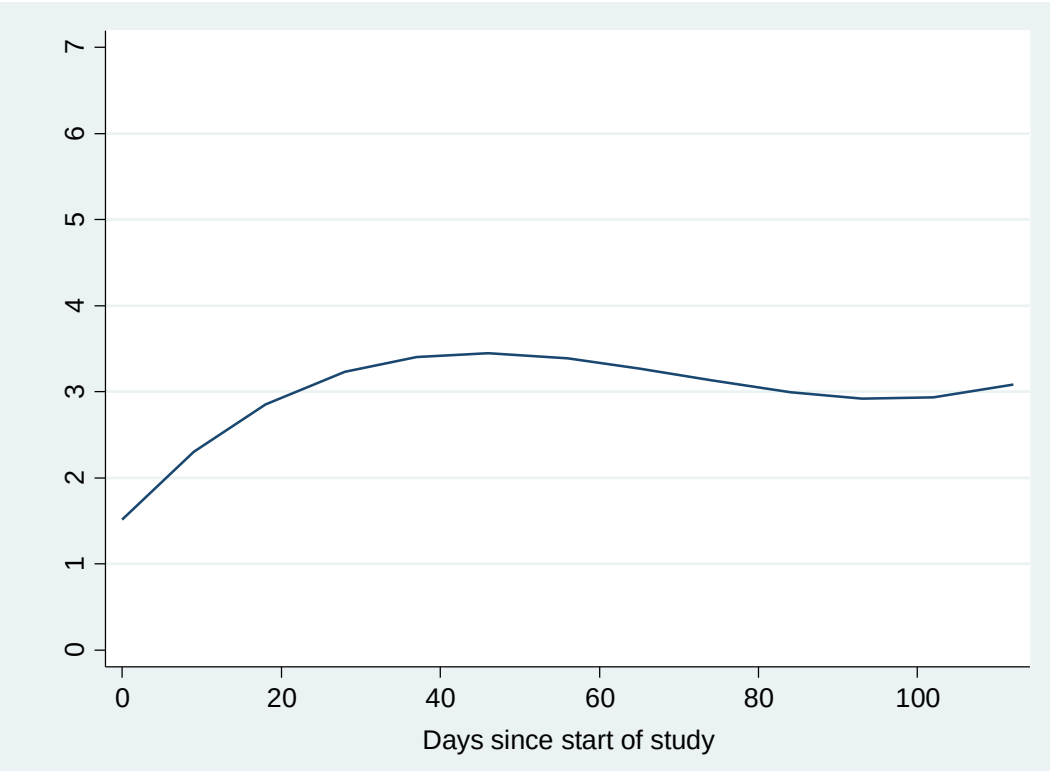

Figure 21 Predicted values of vitamin C automaticity
The graph depicts predicted values for a participant aged 40 years, and with a baseline pleasure score of 4.

The sensitivity analysis was conducted by rerunning the final model with the four participants excluded, to see if any of the variables would now be excluded according to the Wald test. The final model did not change when participants were excluded from the sensitivity analysis, indicating that it was unproblematic to conduct the analysis on the entire dataset.

Regression of baseline predictors of context stability

A regression was constructed with all baseline measurements of the reward and motivation variables. The final, random intercept model, following a backwards elimination procedure, is shown in Table 21. The model includes significant linear, quadratic and cubic effects of time. The only other variable to remain in the model is initial pleasure (b=0.458, p=.008).

Predictor		Regression of vitamin C context stability			
		B	SE	p	Wald test, p
Intercept		2.786	0.890	0.003	
Time group					<.001
	Adj time	0.021	0.011	0.048	
	Adj time squared	10.59~	2.60~	<.001	
	Adj time cubed	0.091~	0.016~	<.001	
Baseline pleasure		0.458	0.168	0.008	

Table 21 Final random intercepts model of vitamin C context stability
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

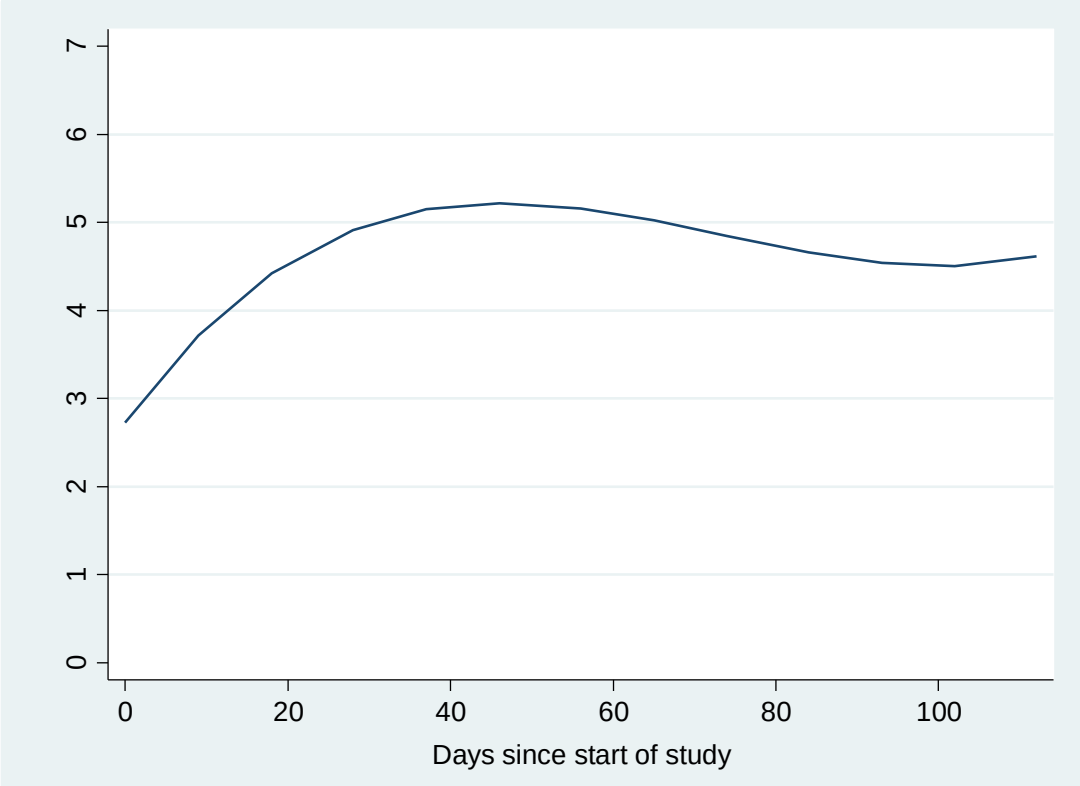

Figure 22 Predicted vitamin C context stability
The graph depicts a participant assuming initial pleasure scores of 4.

The graph of predicted context stability (Figure 22) reveals a steady increase from the start of the study, which plateaued around 40 days, followed by a small decline. The final levels were still higher than the levels of stability at the start of the study.

4.4.3 Structural Equation modelling – testing which variables represent rewards

Vitamin belief

The models were constructed for vitamin belief at T1 and T4, as this variable was not measured at T2 or T3. Vitamin belief did not predict behaviour (p>.190), automaticity (p>.522) or have a significant moderation effect on the behaviour-automaticity relationship (p>.223) in either model. (The full results are shown in Appendix 11.)

The results suggest that contrary to Hypothesis 4b, specific outcome expectancies do not function as a reward, neither by predicting sustained behaviour, nor by strengthening the behaviour-automaticity relationship.

Attitude

At no timepoints was attitude observed to significantly predict behaviour (p>.208), automaticity (p>.223) or to significantly moderate the relationship between behaviour and automaticity (p>.164). While attitude did significantly predict intention (p<.01, with parameter estimates ranging from 0.471 to 0.882), the fact that it did not have a direct or indirect impact on automaticity (except via intention and then behaviour) suggests that believing that a behaviour is generally beneficial, does not have any particular advantage for habit formation, beyond potentially supporting behaviour repetition. (The full results are shown in Appendix 11.)

This suggests that contrary to Hypothesis 4b, acting in accordance with positive attitudes does not function as a reward in reinforcing behaviour.

Pleasure

Several significant pathways were seen from pleasure to automaticity in the models from the different time points. The parameter estimates for each model are presented in Table 22. A diagram of the final model from each timepoint is presented along with a discussion of the findings (Figure 23 - Figure 26).

	Timepoint 1 N=84		Timepoint 2 N=79		Timepoint 3 N=79		Timepoint 4 N=79	
	Coeff	p	Coeff	p	Coeff	p	Coeff	P
Hypothesised predictors of automaticity								
Past automaticity	.113	.516	.501*	<.001	.464*	<.001	.438*	<.001
Behaviour	.172*	.019	.150*	.007	.300*	<.001	.119	.079
Intention	.375	.180	.112	.476	.249	.118	.025	.816
Stability	.164	.356	.186	.100	-.050	.611	.259*	.004
Pleasure	.330	.306	.097	.648	-.067	.700	.380	.097
Pleasure * Behaviour	.031	.594	.109*	.014	.074*	.042	.029	.512
Stability * Behaviour	.099*	.020	.012	.678	.047	.112	.009	.758
Intention * Behaviour	-.061	.202	-.039	.311	-.093*	.017	-.031	.268
Hypothesised predictors of behaviour								
Past automaticity	-.113	.674	-.291*	.029	.054	.706	.237	.094
Intention	.086	.623	.302	.067	.362	.056	.016	.910
Stability	.920*	<.001	.260	.054	.253	.092	.210*	.050
Pleasure	.278	.230	.347	.083	-.042	.833	-.080	.677
Prior behaviour	.057	.497	.675*	<.001	.483*	<.001	.534*	<.001
Hypothesised predictors of past automaticity								
Past behaviour	.037	.420	.432*	<.001	.428*	<.001	.525*	<.001
Hypothesised predictor of intention								
Pleasure	.509*	.001	.698*	<.001	.529*	<.001	.838*	<.001
CFI	.374		.688		.612		.838	

Table 22 Vitamin C SEM results using pleasure as a potentially rewarding variable
Past behaviour and past automaticity refers to behaviour and automaticity measured at the previous timepoint.
The model fit was assessed using the Comparative Fit Index (CFI), where values approaching 1 indicate better fit
*Significant variables are marked with a **

General effects of pleasure on intention, behaviour, and automaticity across all timepoints

The results from the SEM models including pleasure as the rewarding variable are shown in Table 22. At no timepoint did pleasure significantly affect behaviour ($p>.083$). Pleasure predicted intention at all timepoints ($p<.001$) with coefficients ranging from 0.509 to 0.838. However, intention did not significantly predict behaviour ($p>.056$). While it did reach significance at the $p<.1$ level at two timepoints, there is at best limited evidence for the impact of intention on behaviour. Therefore there is little evidence that experiencing greater pleasure from taking vitamin C tablets had an indirect effect on automaticity mediated by increased intention leading to increased behavioural repetition.

Stability was seen to significantly predict behavioural frequency at T1 and T4 ($p<.05$), and to the $p=.1$ level for the other two timepoints. There is therefore some evidence that performing the behaviour in a more stable way leads to more frequent behavioural performance. Past automaticity did not predict current behaviour ($p>.094$), except at T2 ($b=-0.291$, $p=.029$), however as this coefficient was negative, it means that lower past automaticity led to higher future behaviour. Both these findings are unexpected.

Automaticity in the previous timepoint was significantly predicted by behaviour in the previous timepoint ($p<.001$), apart from at T0 ($p=.420$). This finding that baseline behaviour did not predict baseline automaticity is unexpected. Current automaticity was predicted by behaviour in the past week ($p<.019$) with coefficients ranging from 0.150 to 0.300, apart from at T4, when it was not significant ($p=.079$). Apart from at T1, when past automaticity reflects habits prior to the intervention, past automaticity predicted current automaticity at every timepoint ($p<.001$) with coefficients ranging from 0.438 to 0.501. This suggests that automaticity did not vary greatly from T1 onwards, which is supported by Figure 20 in the descriptive statistics section, showing mean automaticity over time. Likewise, past behaviour predicted current behaviour ($p<.001$, $b=0.483$-0.675) apart from at T1, ($p=.497$) when past behaviour was that prior to the intervention.

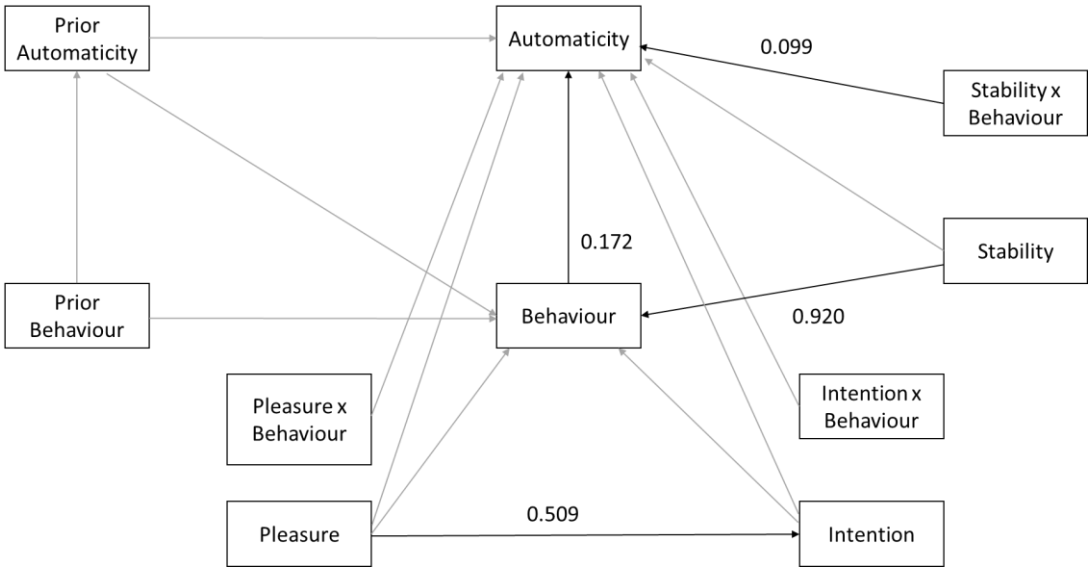

Figure 23 Model predicting vitamin C automaticity at T1, using pleasure as a potentially rewarding variable Grey arrows correspond to non-significant relationships.

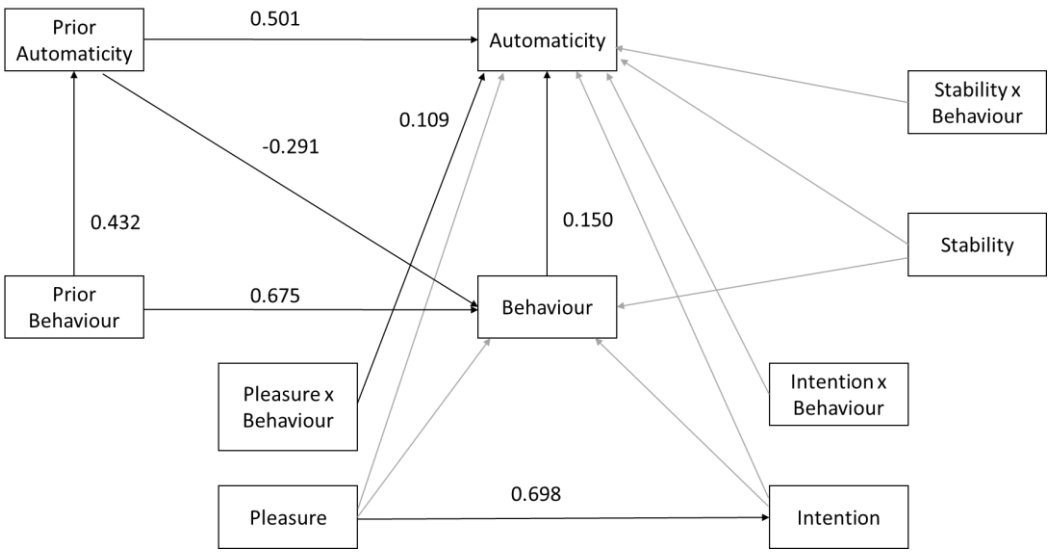

Figure 24 Model predicting vitamin C automaticity at T2, using pleasure as a potentially rewarding variable

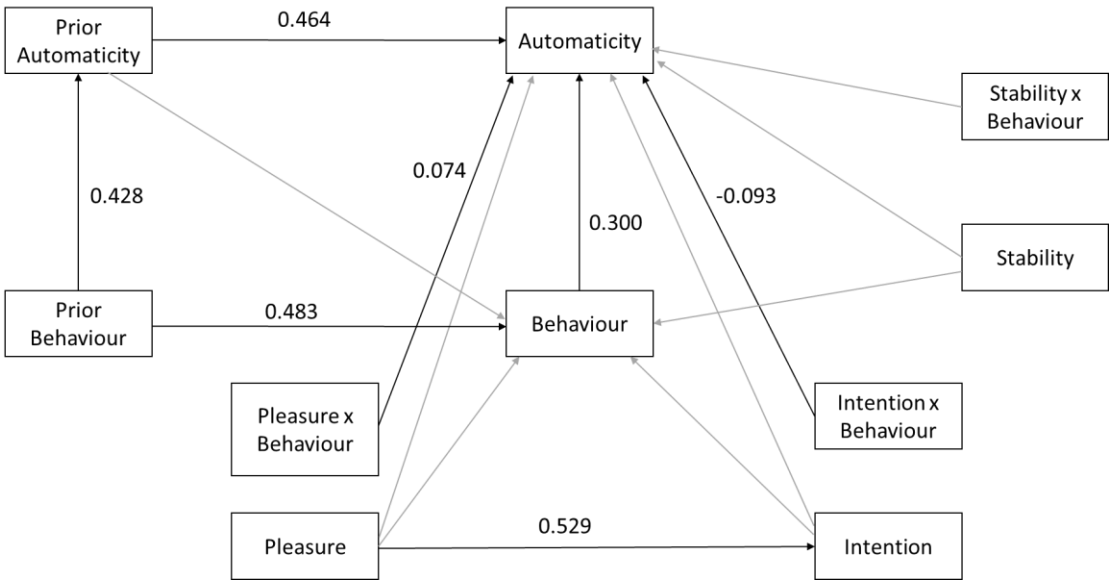

Figure 25 Model predicting vitamin C automaticity at T3, using pleasure as a potentially rewarding variable

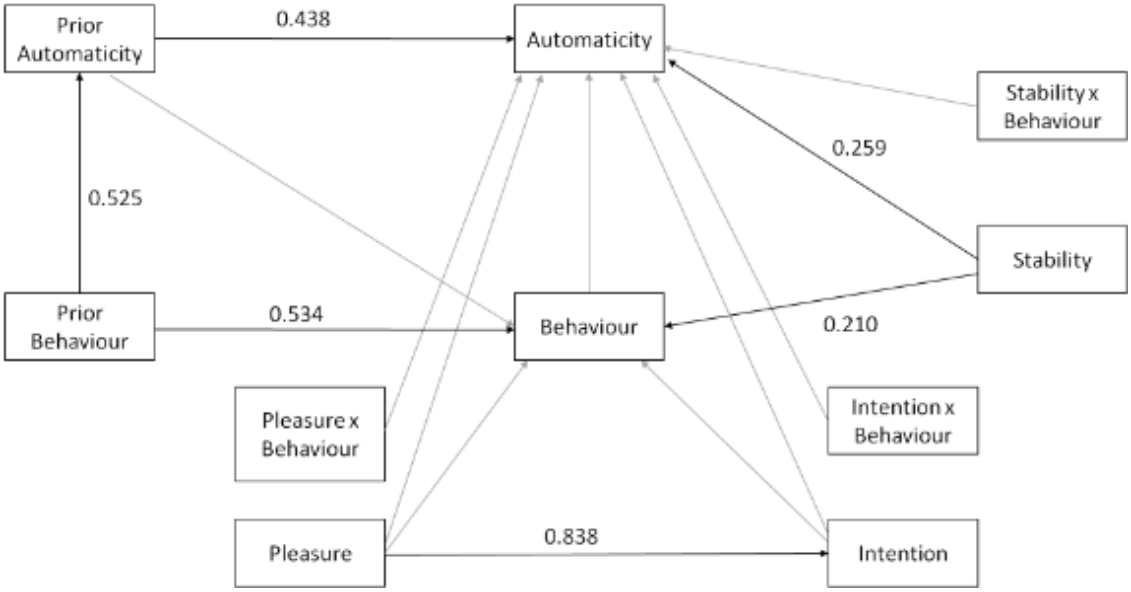

Figure 26 Model predicting vitamin C automaticity at T4, using pleasure as a potentially rewarding variable

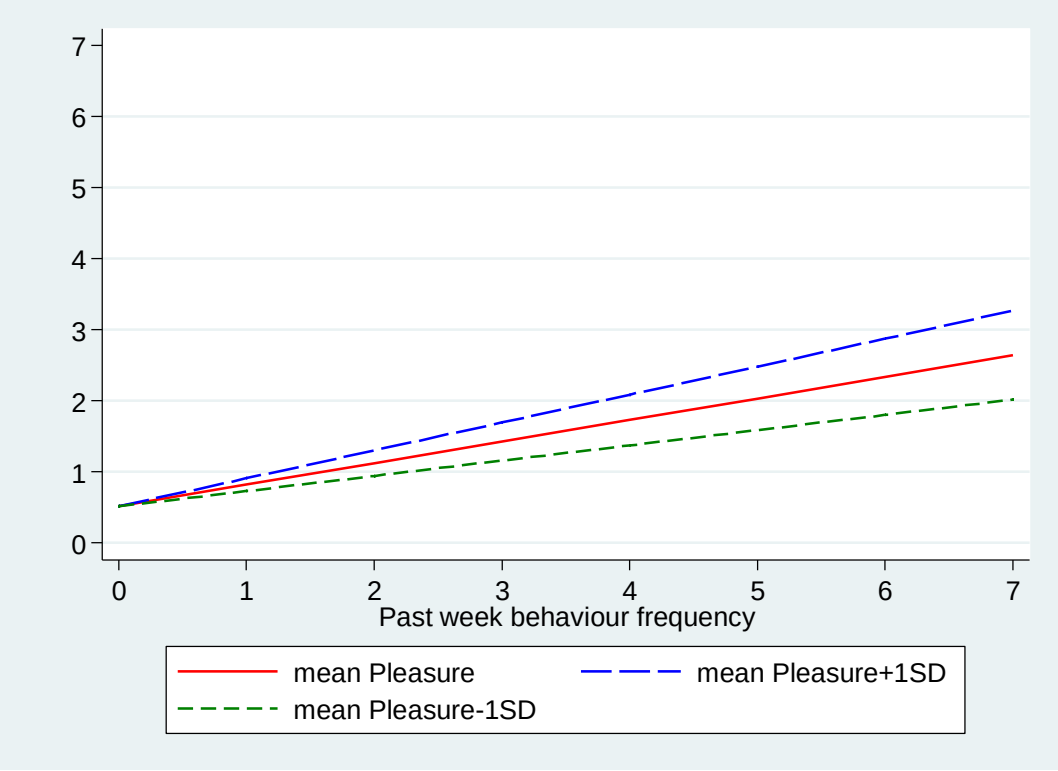

Figure 27 Effect of behaviour on vitamin C automaticity at T3, moderated by pleasure

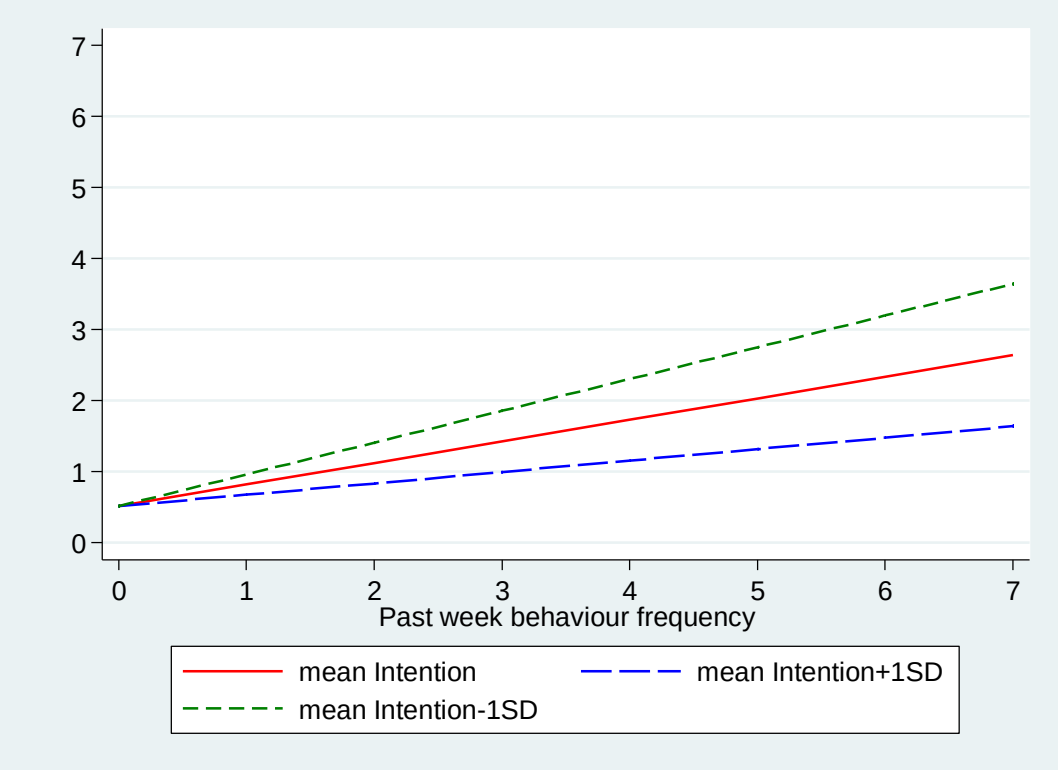

Figure 28 Effect of behaviour on vitamin C automaticity at T3, moderated by intention

Model for pleasure at T1

As shown in Figure 23, at T1 (four weeks following the intervention), context stability moderated the impact of behaviour on automaticity (b=0.099, p=.015) such that participants who had a more stable context for taking vitamin C tablets had a stronger relationship between behaviour repetitions and automaticity. However, this relationship was not seen in the remaining models for pleasure at the other timepoints. There was no impact of pleasure except on intention (b=0.509, p=.001) however, intention did not significantly predict behaviour (p=.623) or automaticity (p=.180) so pleasure was not seen to have even an indirect impact on automaticity at this timepoint.

Model for pleasure at T2

As shown in Figure 24, the interaction term between pleasure and behaviour had a significant effect on automaticity, (b=0.109, p=.014), suggesting that higher scores for pleasure strengthened the relationship between behaviour and automaticity[15]. Surprisingly, behaviour was inversely related to automaticity at T1 (b=0.291, p=.029), so stronger automaticity at T1 was predictive of lower behaviour at T2.

Model for pleasure at Time 3

Figure 25 illustrates that the interaction term between pleasure and behaviour again had a significant effect on automaticity, (b=0.074, p=.042), indicating that higher scores for pleasure strengthened the relationship between behaviour and automaticity. This relationship is shown in Figure 27. At stronger levels of pleasure, each behaviour repetition led to greater gains in automaticity. Intention moderated the behaviour-automaticity relationship (b=-0.093, p=.017), whereby stronger intentions weaken the impact of behaviour on automaticity (Figure 28).

[15] Note, that in order for this to represent a real moderated effect, there needs to be no unmeasured confounding, or measurement error, and the model specification should be correct.

Model for pleasure at Time 4

By T4 at the end of the study (Figure 26), pleasure did not have an impact on behaviour (p=.677) or automaticity (p=.097), or a significant moderation effect (p=.512). Both automaticity and behaviour were predicted only by their past values and by stability.

Summary of effects of pleasure on automaticity

While there was no evidence of an impact of pleasure on sustained behaviour, pleasure was seen to strengthen the behaviour-automaticity relationship at both T2 and T3. This suggests that in accordance with Hypotheses 3 and 4a, pleasure did function as a reward to reinforce behaviour, and rewarding variables were seen to strengthen the behaviour-automaticity relationship.

Intrinsic motivation

Several significant pathways were seen from intrinsic motivation to automaticity in the models from the different time points. The parameter estimates for each model are presented in Table 23. A diagram of the final model from each timepoint is presented along with a discussion of the findings.

General effects of intrinsic motivation on intention, behaviour, and automaticity across all timepoints

The results from the SEM models including intrinsic motivation as the rewarding variable are shown in Table 23. At no timepoint did intrinsic motivation significantly affect behaviour (p=.058 at T1, p>.272 otherwise). Intrinsic motivation predicted intention at all timepoints (p<=.001) with coefficients ranging from 0.278 to 0.493. However, intention did not significantly predict behaviour (p>.098). Therefore there is no evidence that having greater intrinsic motivation for taking vitamin C tablets had an indirect effect on automaticity via increased intention leading to increased behavioural repetition.

Stability was seen to significantly predict behavioural frequency at T1 (b=.884, p<.001), and to the p=.1 level for the other three timepoints. There is therefore some evidence that performing the behaviour in a more stable way led to more frequent behavioural performance shortly after initiation of a new behaviour. Past automaticity did not predict current behaviour (p>.056), except at T2 (b=-0.285, p=.038). As this coefficient is negative, it means that lower past automaticity led to higher future habits. Both these findings are unexpected, yet were observed across both the models with intrinsic motivation, and pleasure. Past behaviour predicted current behaviour (p<.001), with coefficients ranging from 0.490 to 0.688, apart from at T1, (p=.660) when past behaviour was that prior to the intervention.

Automaticity in the previous timepoint was significantly predicted by behaviour in the previous timepoint (b>0.432, p<.001), apart from at T0 (p=.410). This finding that baseline behaviour did not predict baseline automaticity is unexpected.

Current automaticity was predicted by behaviour in the past week (p<.014) with coefficients ranging from 0.167 to 0.280, apart from at T4, when it was not significant (p=.073). Apart from at T1, when past automaticity referred to habits prior to the intervention, past automaticity predicted current automaticity in every timepoint (p<.001) with coefficients ranging from 0.430 to 0.492. This suggests that automaticity did not vary greatly from T1 onwards.

Model for intrinsic motivation at T1

As shown in Figure 29, at T1 (four weeks following the intervention), stability moderated the impact of behaviour on automaticity (b=0.102, p=.017) such that participants who had a more stable context for taking vitamin C tablets had a stronger relationship between behaviour repetitions and automaticity. This relationship was also seen in the T3 model. There was an impact of intrinsic motivation on automaticity mediated by intention (b=0.278, p<.001 for the intrinsic motivation-intention pathway; b=0.744, p=.012 for the intention-automaticity pathway). There were also three different moderation effects on the impact of behaviour on automaticity at this timepoint. Intrinsic motivation had a significant moderation effect (b=0.066, p=.043) such that people who were more intrinsically motivated to perform the behaviour (holding all other predictors constant) had a stronger relationship between behaviour and automaticity, meaning that for a certain level of behaviour frequency, greater levels of automaticity were observed. The relationship is comparable to the one plotted for the moderation of the behaviour-automaticity relationship by the pleasure variable (Figure 27). Intention showed a negative moderation effect (b=-0.117, p=.021), meaning that (when

all other predictors are held constant) those with higher intentions had a weaker relationship between behaviour and automaticity. This is the same relationship as illustrated for the moderating effect of intention in the model using pleasure as the rewarding variable (Figure 28).

	Timepoint 1 N=84		**Timepoint 2 N=79**		**Timepoint 3 N=79**		**Timepoint 4 N=79**	
	Coeff	p	Coeff	p	Coeff	p	Coeff	p
Predictors of automaticity								
Prior automaticity	.159	.356	.492*	<.001	.469*	<.001	.430*	<.001
Behaviour	.186*	.014	.167*	.002	.280*	<.001	.125	.073
Intention	.744*	.012	.034	.840	.223	.215	-.097	.473
Stability	.044	.799	.185	.096	-.050	.615	.246*	.007
Intrinsic motivation	-.183	.319	.078	.475	.008	.946	.246*	.038
Intrinsic motivation * Behaviour	.066*	.043	.056*	.013	.028	.176	.000	.979
Stability * Behaviour	.102*	.017	.016	.577	.060*	.043	.018	.532
Intention * Behaviour	-.117*	.021	-.039	.319	-.090*	.036	-.013	.641
Predictors of behaviour								
Prior automaticity	-.111	.688	-.285*	.038	.024	.869	.276	.056
Intention	.050	.771	.303	.098	.323	.120	.106	.533
Stability	.884*	<.001	.259	.059	.256	.089	.199	.063
Intrinsic motivation	.210	.058	.120	.272	.039	.742	-.112	.315
Prior behaviour	.036	.660	.688*	<.001	.490*	<.001	.523*	<.001
Predictors of prior automaticity								
Prior behaviour	.038	.410	.432*	<.001	.428*	<.001	.525*	<.001
Predictors of intention								
Intrinsic motivation	.278*	<.001	.411*	<.001	.384*	<.001	.493*	<.001
CFI	.379		.714		.608		.856	

Table 23 Vitamin C SEM results using intrinsic motivation as a potentially rewarding variable

Model for intrinsic motivation at T2

As shown in Figure 30, the interaction term between intrinsic motivation and behaviour had a significant effect on automaticity, b=0.056, p=.013, suggesting that participants with higher scores for pleasure had a stronger relationship between behaviour and automaticity. While intrinsic motivation had a significant impact on intention (b=0.411, p<.001), intention did not significantly impact upon behaviour or automaticity at this timepoint. Therefore, the moderation effect was the only effect of intrinsic motivation on automaticity at T2. There was no impact of context stability. At T2, past automaticity had a negative effect on current behaviour (b=-0.285, p=.038).

Model for intrinsic motivation at T3

The significant variables in the model at T3 are illustrated in Figure 31. Intrinsic motivation did not have any significant impacts on behaviour or automaticity at this timepoint. Intention again mediated the behaviour-automaticity relationship (b=-0.090, p=.036), such that those with stronger intentions had a weaker relationship between behaviour and automaticity. There was also a significant interaction effect for stability (b=0.060, p=.043), suggesting that people who took their vitamin C tablets in a more stable context had a stronger relationship between behaviour repetitions and automaticity.

Model for intrinsic motivation at T4

By T4 (the end of the study), no significant moderation effects were observed (see Figure 32). Intrinsic motivation had a direct impact upon automaticity (b=0.246, p=.038), as did context stability (b=0.246, p=.007), suggesting that participants with more intrinsic motivation of behaviour, or those who performed the behaviour in a more stable way were more likely to have higher automaticity at T4, and that this effect was independent of behavioural frequency. Current behaviour no longer had a significant impact upon current automaticity at this stage (p=.073). Intention did not have any impact upon behaviour or automaticity at this timepoint.

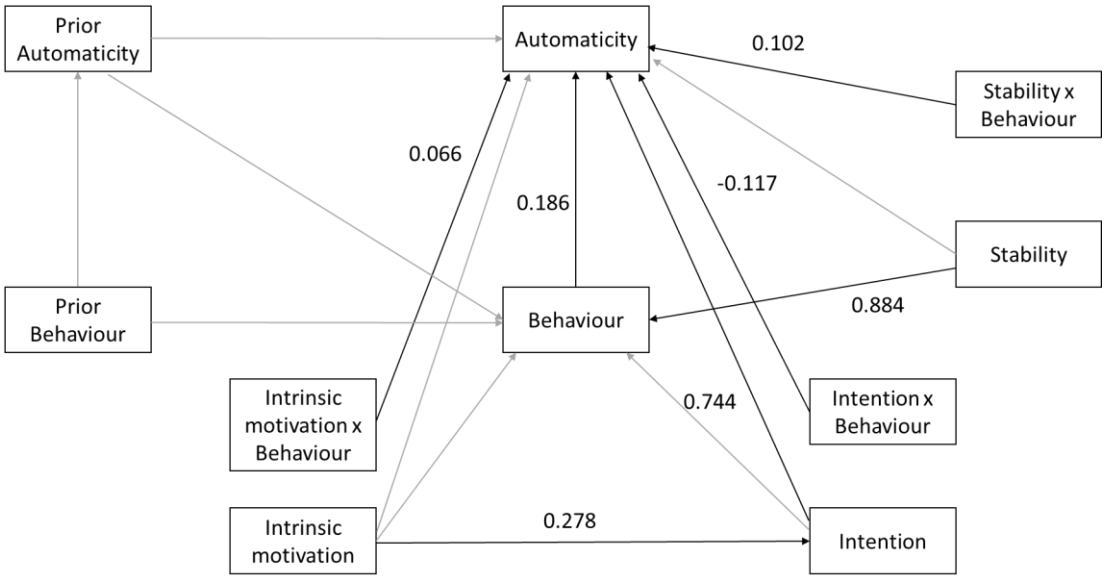

Figure 29 Model predicting vitamin C automaticity at T1, using intrinsic motivation as a potentially rewarding variable

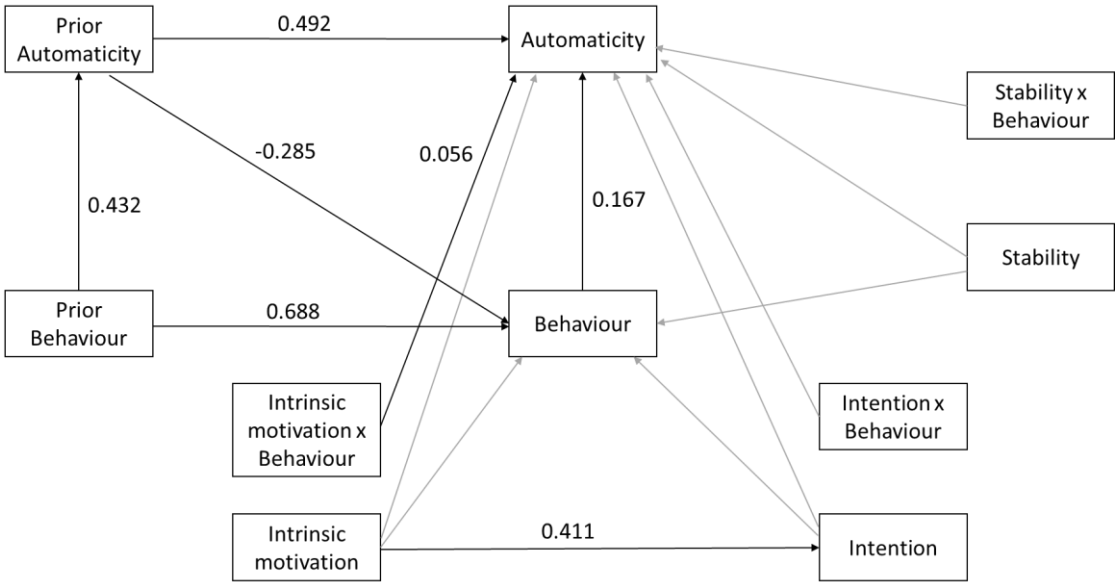

Figure 30 Model predicting vitamin C automaticity at T2, using intrinsic motivation as a potentially rewarding variable

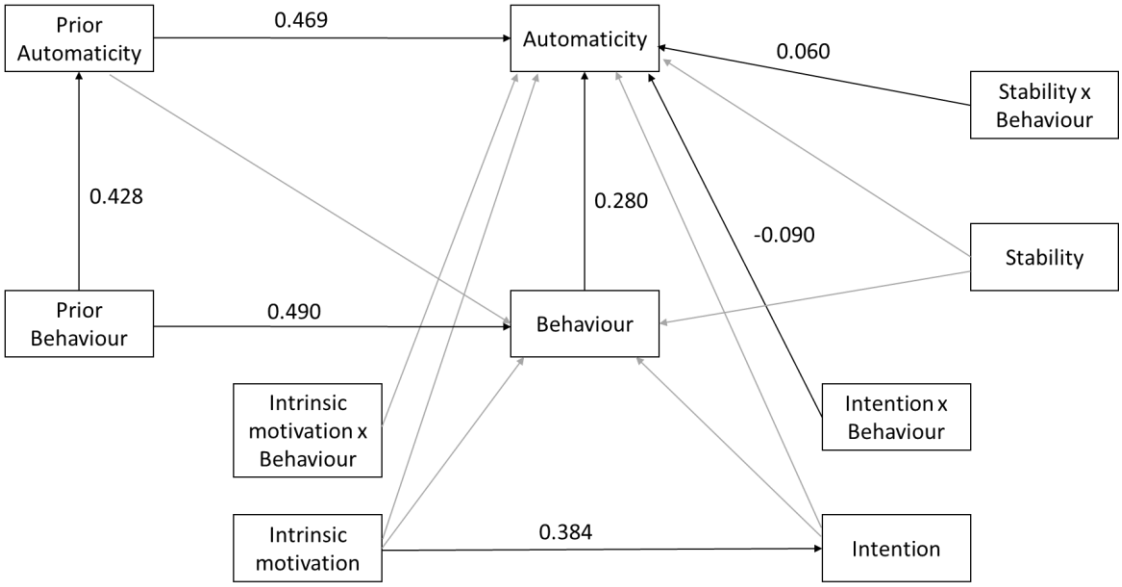

Figure 31 Model predicting vitamin C automaticity at T3, using intrinsic motivation as a potentially rewarding variable

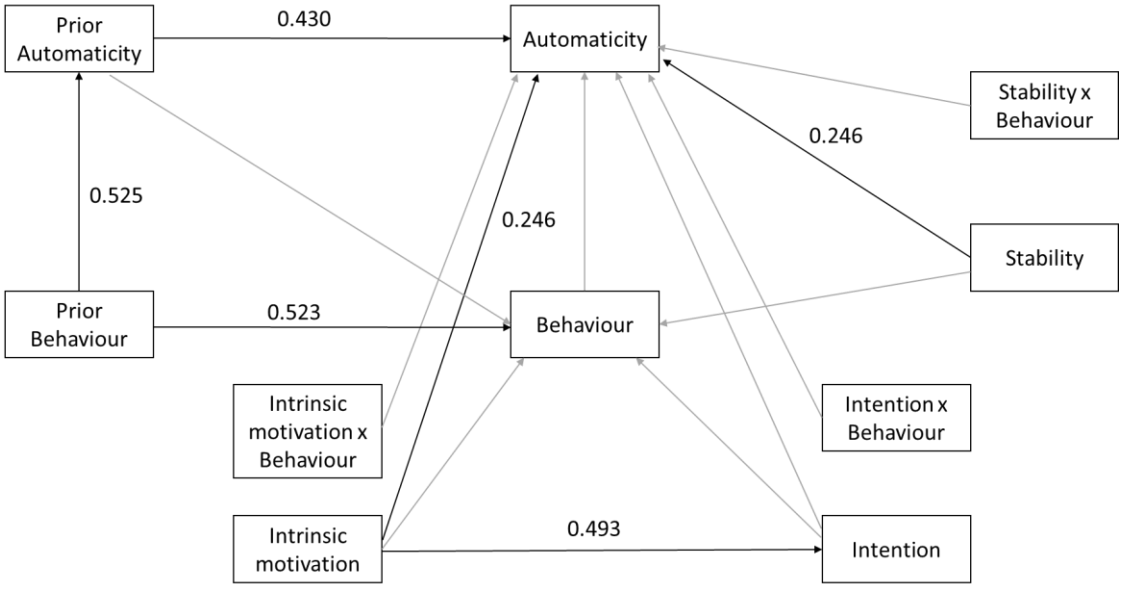

Figure 32 Model predicting vitamin C automaticity at T4, using intrinsic motivation as a potentially rewarding variable

Summary of effects of intrinsic motivation on automaticity

While there was no evidence of an impact of intrinsic motivation on sustained behaviour, at both T1 and T2, intrinsic motivation was seen to strengthen the behaviour-automaticity relationship. At T4, intrinsic motivation had a direct effect on automaticity. These findings suggest that in accordance with Hypotheses 3 and 4c, intrinsic motivation did function as a reward to reinforce behaviour.

4.5 Discussion

4.5.1 Summary

There is support that rewarding variables do promote gains in automaticity. Of the four types of proposed rewarding variables, experiencing taking vitamin C tablets as being pleasurable, and being intrinsically motivated to perform the behaviour, were observed to have a beneficial impact upon automaticity. Having positive beliefs about the outcomes of taking vitamin C tablets, either believing them to be generally beneficial, or believing in specific benefits of taking vitamin C tablets (e.g. shorter or milder colds, reduction in risk of cardiovascular disease), did not have an impact upon behaviour or automaticity.

4.5.2 Potential reward types

Given that some variables were observed to reinforce behaviour and promote automaticity gain, this suggests that it is possible for psychological variables to act as rewards. Each variable that was investigated as a potential reward is discussed in turn.

Reward as general attitude

Attitude was not seen to predict behaviour or automaticity, and so acting in line with positive attitudes was not found to be rewarding. This is true for both specific beliefs regarding the outcomes of taking vitamin C tablets, and more general attitude about whether taking vitamin C tablets is useful or not. There was evidence that these attitude variables increased intention,

but intention was not always found to be predictive of behaviour. Therefore while attitudes may at times have an impact on automaticity mediated by both intention and behaviour, it suggests that positive attitudes are not a key predictor of habit formation.

This seems to be contrary to the findings of another habit formation study, which found that attitude predicted flossing automaticity after four weeks (Judah et al., 2012). However, the analysis of this study did not take into account mediation or moderation effects, so the results could not preclude an effect of attitude solely mediated by intention and behaviour. The addition of the variables of past behaviour, intention and context stability, may have resulted in less variance in behaviour or automaticity being explained by attitudes than may have been expected otherwise. However, the inclusion of these variables allows a more complete view of the habit formation process, in line with current knowledge of determinants of habits and behaviour (Lally & Gardner, 2013; Verplanken & Wood, 2006).

A study of medication adherence showed that beliefs related to the prescribed treatment predicted the time from initial prescription to quitting of the medication, however it did not predict the proportion of doses taken by those who did not quit the medication (Cooper et al., 2010). As full adherence is likely to be driven by habits, this study appears to be consistent with the present finding that attitudes do not predict automaticity gain. Therefore, doing something which is pleasurable was found to be rewarding.

Reward as pleasure

Pleasure was seen to strengthen the relationship between behaviour and automaticity gain at two timepoints in the study. The observation that pleasure was seen to be a rewarding variable is unsurprising, as this is what is observed in animal studies of habit formation (Broadbent et al., 2007). Just as positive sensory experience from food consumption is seen to lead to habit formation in animals, likewise it appears that reported pleasure, or positive sensory experiences in humans also leads to habit formation. The theoretical expectation that humans and animals may share models of behaviour generation is supported by the Associative Cybernetic model (de Wit & Dickinson, 2009), where it is discussed in terms of food consumption. While the present study was not looking at food consumption behaviour, the pleasure variable did measure the hedonic value of the target behaviour of taking vitamin C tablets.

The role of dopamine has been implicated in the process by which goal-directed behaviour becomes habitual (Faure et al., 2005; Hilario & Costa, 2008; Wickens, Horvitz, Costa, &

Killcross, 2007), and in the balance between habitual and goal directed action in humans (de Wit, Standing, et al., 2012), which is consistent with the finding that experiencing something to be pleasurable is associated with reinforcement of behaviour and promotion of habit formation. The habit system is an evolutionarily old system, controlled by the basal ganglia (Graybiel, 2008; Packard & Knowlton, 2002; Yin & Knowlton, 2006). Equivalent brain regions have been observed to predict goal-directed and habitual action between humans and rats (Balleine & O'Doherty, 2009). Therefore it may not be surprising that consistent with work on habit formation in animals, pleasure is important in human habit formation. Likewise, these parallels between habitual behaviour production in humans and animals may explain why longer term considerations about the perceived usefulness of a behaviour do not have a positive impact, except beyond whatever impact they may have on intention to perform the behaviour.

Reward as intrinsic motivation

The other variable which was observed to be rewarding was intrinsic motivation. This strengthened the behaviour-automaticity relationship at two timepoints in the study, and also had a direct effect on automaticity at another timepoint. While an effect of intrinsic motivation is not suggested by habit theory per se, there is empirical evidence that intrinsic motivation has been associated with automaticity, and that it strengthens the behaviour-automaticity relationship for established habits (Gardner & Lally, 2013; Wiedemann et al., 2014).

Intrinsic motivation is well established as a more effective means to sustained behaviour change than extrinsic motivation (Baldwin et al., 2009; Ryan & Deci, 2000). There is evidence that an intervention encouraging intrinsic motivation was found to be more effective than a control group (based on standard dental practice) in encouraging good dental health behaviour and reduction in plaque and gingivitis over a seven month period (Halvari & Halvari, 2006). Encouraging intrinsic motivation has been previously suggested as a means to habit formation, as it is a predictor of ongoing repetition of behaviour, which would subsequently be expected to lead to habit formation (Lally & Gardner, 2013). Following external instructions may lead people to perform actions which they may otherwise not be motivated to do, and the provision of extrinsic, tangible rewards may decrease intrinsic motivation as behaviour is perceived to be directed by outside influences (Ryan & Deci, 2000). Extrinsic rewards may also lead to an increased perceived contingency between the behaviour and reward, which keeps

activity goal-directed rather than becoming habitual (Colwill & Rescorla, 1985; Wood & Neal, 2009).

However, the present findings extend the importance of intrinsic motivation further. The effects of intrinsic motivation on behaviour were observed to be limited; instead being more intrinsically motivated increased the impact of each behavioural repetition on automaticity gain. Therefore, encouragement of intrinsic motivation should be seen as a goal of interventions intending to promote habit formation, and sustained behaviour change, as intrinsic motivation appears to increase the impact of each behaviour repetition on automaticity gain.

4.5.3 Effect of reward on automaticity

The lack of an effect of the variables found to be rewarding (either intrinsic motivation or pleasure) on behaviour, even an effect mediated by intention, was unexpected (Rothman et al., 2009). However, it may be the case that the inclusion of additional variables in the model, such as past behaviour, intention and context stability, may have explained a lot of the variation in behaviour that reward might otherwise have been correlated with. Yet these variables still had an impact upon automaticity, despite no measured effect on behaviour.

At two timepoints during the study, both rewarding variables, of pleasure and intrinsic motivation, were seen to moderate the behaviour-automaticity relationship, whereby stronger reward experienced strengthened the relationship between behaviour and automaticity. This is consistent with theories of reinforcement learning, such as the Associative Cybernetic model (de Wit & Dickinson, 2009; Dickinson, 1985), whereby a reward positively reinforces a behaviour by strengthening the connection between a stimulus (which may be the context) and the response. The more rewarding a behaviour is, the greater the reinforcement may be expected to be, resulting in greater gains in automaticity for a given level of behaviour. This moderation of the behaviour-automaticity relationship by intrinsic motivation has been observed before in terms of existing habits (Wiedemann et al., 2014), but the present study demonstrates this effect for the formation of a new habit.

Intrinsic motivation also had a direct effect on automaticity at the end of the study, sixteen weeks following the intervention. This was not theoretically expected, as rewards are not thought to act upon automaticity completely independent of behaviour, however, it is consistent with some findings from previous studies (Gardner & Lally, 2013; Judah et al., 2012). These studies did have certain limitations, such as studying only existing habits rather than

new habits (Gardner & Lally, 2013), or not taking into account potential moderation or mediation in the analysis (Judah et al., 2012). However, a direct effect from reward to automaticity was only observed at one timepoint for one of the reward types, so the evidence for this relationship is weak. Furthermore, this observed relationship may be due to measurement error (such as from self-report behaviour of habit measures), which would violate the model assumptions and reduce the reliability of the results. Alternatively, there may be other variables on the causal pathway from reward to automaticity which were not measured. This should be investigated further in future studies.

4.5.4 Other general findings

Effect of intention on behaviour and automaticity

No significant effect of intention on behaviour was observed at any timepoint, for either the model including pleasure, or including intrinsic motivation. While intentions have been demonstrated to have a weaker impact upon behaviour when behaviours are frequently performed (and thus potential candidates for habit formation) (Webb & Sheeran, 2006), some impact of intentions would still have been expected. However, the inclusion of past behaviour within the models may have reduced the explanatory effect attributed to intention. At two timepoints for the model including pleasure, and for one timepoint for the model including intrinsic motivation, the pathways did reach significance at the 0.1 level. This suggests that intention may have an impact upon behaviour, but there was not enough power to detect it here. However, the lack of a strong impact of intention on behaviour suggests that intention is not as important in predicting behaviour as sometimes suggested (Webb & Sheeran, 2006).

For both models, at twelve weeks following the intervention, having stronger intention for the behaviour was found to weaken the effect of behavioural repetitions on automaticity gain. This may reflect the fact that those who are still performing the behaviour intentionally at this point are less likely to be doing it automatically.

There was also a consistent effect observed between reward variables and intention. This may be understood as enjoying an activity is likely to result in wanting to perform that activity in the future. This is consistent with the claim that satisfaction with a behaviour leads to maintenance (Rothman, 2000).

Effect of context-dependent repetition on behaviour and automaticity

Habits are described to form by context-dependent repetition (Lally & Gardner, 2013; Lally et al., 2010). At different timepoints, context stability was observed to have an impact on behaviour, a direct effect on automaticity, and to strengthen the behaviour-automaticity relationship. The effectiveness of performing healthy infant feeding behaviour in a constant context has been demonstrated to be beneficial for behavioural maintenance and repetition (McGowan et al., 2013). Yet few other studies have explicitly tested or measured the effect of performing a behaviour in a stable context on the development of a habit. The present study provides further empirical support (albeit correlational) from a habit formation perspective that context-dependent repetition is an important predictor of automaticity.

At certain timepoints, higher levels of context stability were observed to predict higher levels of behaviour, and therefore have an effect on automaticity mediated by behaviour. This can be explained, as performance in a regular context (measured here in terms of location, and point within a routine) is more likely to be repeated, due to aspects of the stable context being a more effective reminder for the behaviour. Higher levels of repetition would subsequently lead to greater automaticity.

Context stability was also observed to moderate the behaviour-automaticity relationship, whereby higher levels of context stability strengthen the impact of behavioural repetition on automaticity. This may be expected, as if a behaviour is performed in a stable context, each repetition would lead to greater automaticity gain due to the strengthening of associations between the specific context and the behaviour. If the behaviour is performed in many different situations, it would be harder to associate situational cues with the behaviour, and so context dependent automaticity would be less likely (Lally & Gardner, 2013). Direct effects of context stability were also observed. This may be due to model limitations, such as measurement error, or another unmeasured variable on the causal pathway.

Relationship between behaviour and automaticity at baseline

A significant effect of baseline behaviour on baseline automaticity was not observed. This is surprising as prior to the intervention, it would be expected that behaviour and automaticity would be highly correlated (Gardner et al., 2011; Verplanken & Orbell, 2003). This may be understood with reference to habits of initiation versus habits of execution (Gardner, 2014; Maddux, 1997). A habit of initiation refers to the automaticity inherent in selecting a

behaviour, for example, if someone automatically decides to take their medication, without making a conscious decision. A habit of execution would mean that after deciding to take their medication, the person takes out a tablet, puts it in their mouth and swallows it without thinking about what they are doing. It is possible to have both a habit of initiation and a habit of execution, or just one of either a habit of initiation or a habit of execution. The distinction between the two, and how they might be measured, has not been well researched.

Habits of initiation may be expected to correlate with behaviour frequency, and are likely to be the intended construct measured by automaticity questionnaires (because when habit research is pursued as a means to understanding and promoting healthy behaviour change, then habitual initiation rather than execution of the target behaviour is of primary interest, as this would be expected to relate to the frequency of the behaviour). However, for a person with a habit of execution but not a habit of initiation, although the behaviour may be performed very infrequently, when the behaviour does occur, the steps involved would be performed automatically, requiring minimal conscious deliberation. It may be expected that there would be a low correlation between the habit of execution and behaviour frequency. The observation that baseline rates of behaviour and automaticity do not correlate well may suggest that participants are answering the SRBAI questions in terms of execution rather than initiation habits. A tendency to answer about execution rather than initiation may be greater if the behaviour is infrequently performed, as participants may have a bias to responding positively to questionnaires (Paulhus, 1991). If this suggestion is correct, it has an implication for self-report habit measurement in general, as it raises the possibility that questionnaires are not measuring the intended facet of automaticity. This issue should be investigated further in future research.

4.5.5 Limitations

While the findings of this study are interesting, and an important contribution given that they relate to habit formation following an intervention, they are still limited as they are only correlational. There was no attempt to test the effectiveness of manipulating the different potentially rewarding variables. (The present study aimed to identify variables which may serve as rewards for future intervention research, and therefore could not be designed to manipulate all four hypothesised variables.) Furthermore, the strong correlations between the candidate rewarding variables may have made it difficult to tease apart the differential effects of the different variables. However, the findings shed light on the features which may act as

rewards and reinforce behaviour, and these can be tested in interventions studies in the future.

It is important to note that the analysis is this chapter was only based on 80 participants, and there was therefore less power to detect effects compared to the analysis of flossing habit formation. (Furthermore, the sample size was not calculated to address the hypotheses about reward due to the nature of the analysis, therefore, even for flossing, the required sample size was not known beforehand.) Despite the smaller sample size, the expected effects of reward were observed for the variables of pleasure, and intrinsic motivation. However, it may be claimed that the null findings for general attitude and vitamin belief were due to a lack of power. Yet a consideration of the coefficients for the effects of these variables on behaviour and automaticity reveals that at most timepoints, the coefficients were either very small or negative, in addition to being far from significance. Therefore, it seems unlikely that the lack of observed effect for general attitude and vitamin belief on automaticity was due to insufficient power to detect an effect.

The stem for the vitamin SRBAI did not include any reference to context. As habits are seen as the process by which a stimulus automatically prompts a particular behaviour, the absence of a specified stimulus or cue in the questionnaire measure may have introduced measurement error. This is hard to rectify, as different participants were likely to have taken their vitamin C tablets in different situations, or at different times of day. Incorporating this context variability into a questionnaire may have practical difficulties, and allowing participants to specify their own context may lead to contextual cues of different levels of specificity being chosen, which would reduce comparability of the results between participants. This is an issue which should be considered further in future habit and habit formation studies.

In addition, there may be some circularity in the consideration of reward. One of the hypotheses tested was establishing whether rewards have a certain characteristic, and the other was identifying whether different variables have the function of reward. However, variables were only classified as being rewarding if they had the characteristic (of strengthening automaticity) that was being tested, leading to the interdependence of each hypothesis on the other. However, there was a strong theoretical expectation that rewards should strengthen the behaviour-automaticity relationship. The idea that pleasure should be rewarding is also strongly supported. Therefore the parallel relationships observed with pleasure and reward on automaticity may mean that the approach taken was justified and that the findings are valid.

4.5.6 Conclusions

The present study demonstrated that pleasure and intrinsic motivation act as rewards, by strengthening the impact of behaviour repetitions on automaticity gain, when forming a habit for taking vitamin C tablets. General attitude, or specific beliefs about the benefit of taking vitamin C tablets did not have this effect. While the moderation effect was not seen at every timepoint, the results clearly demonstrate that the impact of the rewarding variables on automaticity was not merely mediated by greater levels of behaviour. These findings should be applied to design behaviour change interventions with greater ability to accelerate the habit formation process. Practical recommendations will be explored in the discussion chapter.

Chapter 5: Results - Individual differences in habit formation

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5.1 Background

A key study monitoring the formation of habits over time found considerable variation between individuals, both in the time taken for habits to form, and the strength of final habits (Lally et al., 2010). This observed variation in habit formation has been used to suggest that additional variables may predict habit formation, but also leads to the possibility that individuals may differ in their tendencies to form habits. This assertion of individual differences in the tendency to behave habitually, has been supported by studies of associative learning (Byrom, 2013), and by both neurological and behavioural findings in humans (de Wit, Watson, et al., 2012; Sjoerds et al., 2013), and rats (McIntyre et al., 2003). However, the

predictors of tendencies to habits observed in these studies, were factors such as corticostriatal connectivity, or acetylcholine release in the hippocampus, which are not easily measured. It has also been suggested that traits or dispositional factors such as optimism and conscientiousness may predict persistence with a behaviour change attempt despite obstacles (Carver & Scheier, 1982; Scheier & Carver, 1985), and that temperament types predict differences in habit formation in dogs (Windholz, 1998).

In this chapter, individual difference factors (those describing variations between people in traits or characteristics) were considered for their impact upon behaviour repetition and habit formation. The variables selected for investigation were either related to features known to be important in habit or the habit formation process, or they have been observed empirically to be related to habitual behaviour. The variables under investigation were, prospective memory ability (McDaniel & Einstein, 2007), Big 5 personality constructs (John & Srivastava, 1999), personal need for structure (Neuberg & Newsom, 1993), and rational or experiential thinking style (Pacini & Epstein, 1999).

Prospective memory is the ability to remember to do something in the future. It is also referred to as the performance of delayed intentions (McDaniel & Einstein, 2000). Remembering to perform a new intended activity is a vital step in behaviour initiation, and success in initiation may therefore affect subsequent behaviour repetition and automaticity. Prospective memory ability was found to be associated with levels of flossing behaviour for the four weeks following an intervention (Judah et al., 2012). The present study will investigate the impact of prospective memory upon initiation and repetition, which would then be expected to encourage subsequent automaticity gain.

Personality types may also be related to either the ability to initiate a new behaviour, or the likelihood of forming habits. Behaviours which may be considered to be habitual, such as chewing gum or compulsive buying, have been observed to be related to consistent traits such as high neuroticism and extraversion (Bivens et al., 2013; Malouff et al., 2006; Smith, 2009). In addition, the tendencies of self-control and orderliness consistent with the trait of conscientiousness would be expected to aid in behaviour initiation and repetition (Roberts et al., 2009).

Habit formation is known to require the behaviour to be repeated in a constant context (Lally & Gardner, 2013). Personal need for structure is a measure of how much someone prefers an ordered and structured life (Neuberg & Newsom, 1993), and may be associated with the tendency to follow routines more rigidly (Giovannetti, Schwartz, & Buxbaum, 2007b). This would be expected to facilitate initiation of a new behaviour due to increased stability of prior-

action cues. In addition, the higher likelihood of the behaviour being repeatedly performed in a stable context would predict greater habit formation, which is not only mediated by increased behaviour frequency.

The automatic rather than reflective system of dual process models has been related to the production of habitual behaviour (Wood et al., 2014), as habits activate behaviour automatically. Rational thinking style has been related to the reflective system, as both are described as logical, deliberative, and show slower processing. Experiential thinking style is related to the automatic system, as it is associative, rapid and unconscious. Individuals may differ in their preferences for experiential and rational thinking style, which can be measured using the Rational and Experiential Inventory (Pacini & Epstein, 1999). The comparability between thinking style, dual process models, and habits suggests a theoretical expectation for the trait of thinking style to be associated with the tendency to act in a habitual way. In addition, doctors with greater preference for the experiential rather than rational thinking style were observed to show great hand hygiene compliance (Sladek et al., 2008). As handwashing is considered to be a habitual behaviour (Aunger et al., 2010), the observation from the study by Sladek et al gives empirical support to the claim that current habits are related to experiential thinking style. The present study provides an opportunity to test whether this association holds for the formation of new habits. As thinking style is expected to be a trait related to the inherent tendency to behave more habitually, the effect of experiential style on automaticity would not be expected to be solely mediated by behaviour repetition.

It will be investigated whether each factor is associated either with behaviour and automaticity. This analysis will examine whether certain variables are associated with increased behavioural performance and subsequent habit formation. The analysis will also be conducted by testing all variables in combination, to see which effects remain when all significant traits are taken into account.

To my knowledge, this is the first investigation of such individual difference effects in a prospective study of habit formation, rather than using them to predict differences between individuals in existing habits or behaviour. Different factors may be expected to predict between-subject differences, as opposed to the likelihood for behaviour repetition and habit formation (Weinstein, 2007). Inferences should not be made about predictors of an individual level process from predictors of variation between individuals (Molenaar, 2004). In addition, a study of formation can investigate more precisely whether individual difference variables affect initiation, maintenance or habit formation. This would have the benefit of informing theory of habit formation through knowledge of predictors at different stages of the process.

In addition, knowledge of traits which may hinder habit formation at specific stages could inform tailored interventions to assist people at the stages when they are likely to need it most.

The hypotheses tested in this chapter are:

H5: Higher prospective memory ability will be associated with greater initiation rates of a new behaviour.

H6: Personality traits as measured by the Big 5 will relate to the likelihood of maintaining a new behaviour, and of forming stronger habits.

H7: People with a stronger personal need for structure will be more likely to initiate and maintain a new behaviour, which is likely to lead to increased likelihood of forming stronger habits.

H8: Preference for experiential as opposed to rational thinking style will be associated with the tendency to form stronger habits.

Table 24 summarises the expected effects of each individual difference (ID) variable on the different stages of the habit formation process.

ID variable	**Expected to be a predictor of:**		
	Initiation	Maintenance	Automaticity gain
Prospective memory	Yes	Yes	Yes
Personality		Yes	Yes
Personal Need for Structure	Yes	Yes	Yes
Thinking style			Yes

Table 24 Expected effects of individual difference variables on the habit formation process

5.2 Methods

Individual difference (ID) variables were measured in the questionnaire at baseline (T0). The measures are discussed in depth in the Methods chapter, but listed again here.

The Big 5 personality traits were measured using a ten item version (Gosling et al., 2003), as shown in Appendix 6. Only the variables for Extraversion, Agreeableness, Conscientiousness

and Emotional Stability were included here, as Openness to experience was excluded as internal consistency measured using Cronbach's alpha was found to be very low (0.18). This variable has not been observed to be empirically associated with habitual behaviour, and therefore the omission of this Big 5 item is not critical for the test of expected relationships.

Personal Need for Structure (PNS) was measured using a twelve item scale as shown in Appendix 4 (Neuberg & Newsom, 1993). Thinking style was measured using the forty item Rational and Experiential Inventory shown in Appendix 5 (Pacini & Epstein, 1999). Prospective memory (PM) was measured using the sixteen item Prospective and Retrospective Memory Questionnaire (Smith et al., 2000), which is shown in Appendix 3.

5.3 Analysis

In order to assess whether automaticity may be an underlying tendency, correlations between the flossing and vitamin C automaticity scores, as well as between the flossing and vitamin C behaviour scores were calculated. As the intervention for vitamin C occurred at T0, and the intervention for flossing occurred at T1, the correlations were calculated matched according to the length of time since the intervention, rather than according to the timepoint of the study. The observation of significant correlations between scores for the two behaviours would suggest that there may be individual tendencies towards performing behaviours more automatically.

The individual difference variables were assessed for normality, and descriptive statistics were conducted to measure the mean and standard deviation of all items. A correlation matrix was constructed to see how the different ID measures were related to one another, and any strong correlations were identified.

The individual difference variables were tested by adding them to each of the four longitudinal regressions of the models for vitamin and flossing behaviour and automaticity (after they were refined using the Wald test), as established in Chapters 3 and 4. This was in order to identify the effects of the ID variables while controlling for other known predictors of behaviour and automaticity. This was a more stringent test of the effects of the covariates, and as many tests have been conducted on a limited dataset, so controlling for the known predictors reduced the likelihood of spurious effects being found due to chance. The original vitamin behaviour model only contained linear time. The original vitamin automaticity model included linear, quadratic and cubic time, age and baseline pleasure scores. The original flossing behaviour

model included the variables of linear, quadratic and cubic time, age and baseline reward. The original flossing automaticity model was the same as for flossing behaviour, but also included baseline scores of descriptive norm, as well as a linear effect of time prior to the intervention[16].

In order to test the impact of each ID variable separately, they were first tested by adding each one individually to each of the four models. Some of the variables may be expected to have different effects at different timepoints in the study. For example, prospective memory would be expected to have a greater effect soon after the intervention, as opposed to later on (because a better ability to act on delayed intentions would have most benefit early in the study, before habits have started to form). Therefore, an interaction term with linear, quadratic and cubic time[17] was included for all of the individual difference variables. The Wald test was used to determine whether the addition of the interaction term with time (taking all three time variables together), and then the variable main effect, significantly improve the model. If the Wald test for the interaction with time is significant, but the individual time estimates are not, then the cubic, and if necessary, quadratic time variables would be removed from the interaction term, until there is consistency between the significance levels for the individual and combined interaction terms with time.

The test of which variables have an overall effect was conducted by adding all the ID variables to the four final models of flossing and vitamin behaviour and automaticity. Interaction terms with linear, quadratic and cubic time were also included for those variables which had significant interactions with time when tested individually. A backwards elimination method using the Wald test was again used to exclude non-significant variables.

5.4 Results

5.4.1 Correlation between flossing and vitamin C behaviour and automaticity

The correlation between the two behaviours under investigation in terms of their behaviour and automaticity scores is shown in Table 25. Significant, medium sized correlations were observed for all comparisons, apart from between the behaviour scores at the point of the

[16] All models were conducted with time adjusted so the intercept represents the end of the study (T4), so the parameter estimates can usefully be interpreted as the effect on final behaviour or automaticity. Flossing automaticity could not be conducted that way, due to missing baseline scores, so this model used unadjusted time, and the intercept represents the point of the intervention (T1).

[17] These three variables for time allow the greatest flexibility to model changing relationships over time.

intervention, which were not correlated. This is unsurprising, as it may not be expected that two unrelated behaviours would correlate. However, following an intervention, it may be the case that trait or individual difference variables would lead to certain people being more likely than others to perform a behaviour following an intervention. This is consistent with the observation of significant correlation scores between the two behaviours following the intervention. It is unexpected that despite no correlation between behaviour at the point of the intervention, automaticity scores are still significantly correlated. This may be simply due to measurement error. However, this finding might also reflect a possibility that some people may experience performing certain behaviours as automatic, even if they are infrequently performed. However, the correlations observed between the automaticity scores for flossing and taking vitamin C tablets were not large. This may be due to the significant effects of reward and other variables, observed within the other chapters, which explain much of the between-person difference in automaticity. Yet the fact that automaticity scores between the two behaviours are significantly correlated throughout the study suggests that it may be reasonable to assume that trait variables may affect how automatically behaviour is performed.

		Flossing			
		Intervention timepoint	**Intervention + 4 weeks**	**Intervention + 8 weeks**	**Intervention + 12 weeks**
Vitamin	**Behaviour**	-.055	.362**	.319**	.449***
	Automaticity	.409*	.366**	.228*	.387***

Table 25 Correlation between flossing and vitamin C behaviour and automaticity scores
Note, that flossing scores at timepoint X are matched with vitamin C scores at timepoint X+1, as the intervention for vitamin C occurred at T0, whereas the intervention for flossing occurred at T1. (So the "Intervention + 4 weeks" measurement refers to T1 for vitamin C and T2 for flossing>"
** p<.05, ** p<.01, *** p<.001*

5.4.2 Summary of variables

All variables were found to be normally distributed. The means and standard deviations of each item are shown in Table 26. For each variable, mean scores were seen that were above the scale midpoint, aside from prospective memory; however for this variable only, high scores denote low prospective memory ability.

Variable	Mean	SD	Possible range
Prospective Memory	2.61	0.75	1-5
Rational Engagement	3.58	0.65	1-5
Rational Ability	3.79	0.59	1-5
Experiential Engagement	3.31	0.52	1-5
Experiential Ability	3.52	0.53	1-5
Personal Need for Structure	4.02	0.92	1-7
Emotional Stability	4.90	1.20	1-7
Conscientiousness	5.30	1.20	1-7
Agreeableness	4.98	1.05	1-7
Extraversion	4.81	1.26	1-7

Table 26 Means and standard deviations of all individual difference variables
For all variables, high scores indicate high ability/reliance on the named individual difference variable, except for prospective memory, where high scores denote low ability.

5.4.3 Correlation between items

Correlations between the ID variables are shown in Table 27. Strong correlations (those above 0.5, (Cohen, 1992)) were not observed between most individual differences measures. The exception was between rational ability and rational engagement, and between experiential ability and experiential engagement, which were significantly and highly correlated. The remaining significant correlation coefficients ranged from -0.291, to 0.347.

	1	2	3	4	5	6	7	8	9	10
1.Emotional Stability	-									
2.Conscientiousness	0.126	-								
3.Agreeableness	0.164	0.068	-							
4.Extraversion	0.066	-0.039	0.049	-						
5.Rational Engagement	0.092	-0.076	0.007	0.215	-					
6.Rational Ability	0.229*	0.157	0.077	0.135	0.699***	-				
7.Experiential Engagement	0.045	0.045	-0.076	0.179*	0.185*	0.236**	-			
8.Experiential Ability	0.218*	0.049	-0.121	0.212*	0.135	0.347***	0.631***	-		
9.Personal Need for Structure	-0.210*	0.268**	-0.102	-0.268**	-0.286**	-0.143	-0.086	-0.057	-	
10.Prospective Memory	-0.246**	-0.291**	0.052	-0.018	-0.038	-0.154	-0.04	-0.171	-0.162	-

Table 27 Correlation matrix of all individual difference variables
**p<.05, **p<.01, ***p<.001. N=122*

5.4.4 Flossing Behaviour

Unadjusted associations between individual differences and flossing behaviour

Table 28 shows the parameter estimates (of the ID variables only) for each of the regression models with the individual difference variables included individually. Prospective memory ability had an effect on flossing behaviour that varied over time (p=.028), with a linear, quadratic and cubic effect. The nature of this effect is illustrated in the plot of the model adjusting for the effect of other individual difference variables (Figure 33). The only significant main effect was a marginally significant main effect of extraversion (b=-0.227, p=.051) which was associated with lower levels of behaviour.

Individual difference variable	**Main effect**		**Interaction with timegroup, when found**	
	B	**p**	**Time variables**	**p**
Prospective Memory	-0.232	.490	Linear, quadratic and cubic	.028
Rational Engagement	-0.273	.236		
Rational Ability	-0.343	.164		
Experiential Engagement	-0.118	.704		
Experiential Ability	-0.100	.731		
Personal Need for Structure	0.152	.374		
Emotional Stability	-0.003	.979		
Conscientiousness	0.054	.667		
Agreeableness	-0.056	.695		
Extraversion	-0.227	.051		

Table 28 Parameter estimates for inclusion of each individual difference model separately within the regression for flossing behaviour

Adjusted associations between individual differences and flossing behaviour

When all ID variables were combined into a single model with the known predictors of flossing behaviour, both extraversion and the interaction between time and prospective memory remained in the model (Table 29). Higher extraversion was associated with lower levels of flossing behaviour (b=-0.231, p=.037). The changing effect of prospective memory over time is illustrated in Figure 33.

As expected, PM scores had a differential effect on flossing behaviour shortly following the intervention. Those with lower PM scores (indicating higher PM ability) showed a faster increase in behaviour immediately following the intervention. The peak levels of behaviour were also higher for those with higher PM ability. Two standard deviations increase in PM ability is seen to be associated with approximately three quarters of a point increase in peak weekly flossing frequency levels. However, following this peak, a greater decline in behaviour was seen by those with higher PM ability, so that regardless of ability, all participants had the same final behaviour levels.

		Regression of flossing behaviour			
Predictor		**B**	**SE**	**p**	**Wald test, p**[18]
Intercept		2.882	1.289	0.027	
Time group					<.001
	Adj time	0.098	0.066	0.140	
	Adj time squared	52.30~	21.33~	0.015	
	Adj time cubed	0.55~	0.17~	0.001	
Age		0.034	0.015	0.023	
Baseline reward		0.418	0.125	0.001	
Extraversion		-0.231	0.115	0.047	
Prospective memory		-0.211	0.325	0.518	
Prospective memory * Timegroup interaction					.026
	PM * Adjusted time	-0.030	0.024	0.211	
	PM * Adjusted time squared	-13.4~	7.75~	0.086	
	PM * Adjusted time cubed	-0. 1~	0.062~	0.042	

Table 29 Final regression model for flossing behaviour, including significant individual difference variables
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

[18] As the linear, quadratic and cubic effects of time are included in the model, and tested for their inclusion in combination using the Wald test, in these cases the Wald test is different from the p values of the final model. Therefore, for the test of the combination of time effects, and for the interaction terms, the Wald test is cited in the tables in order to indicate whether the parameter estimates for the individual variables should be interpreted as being important in the model.

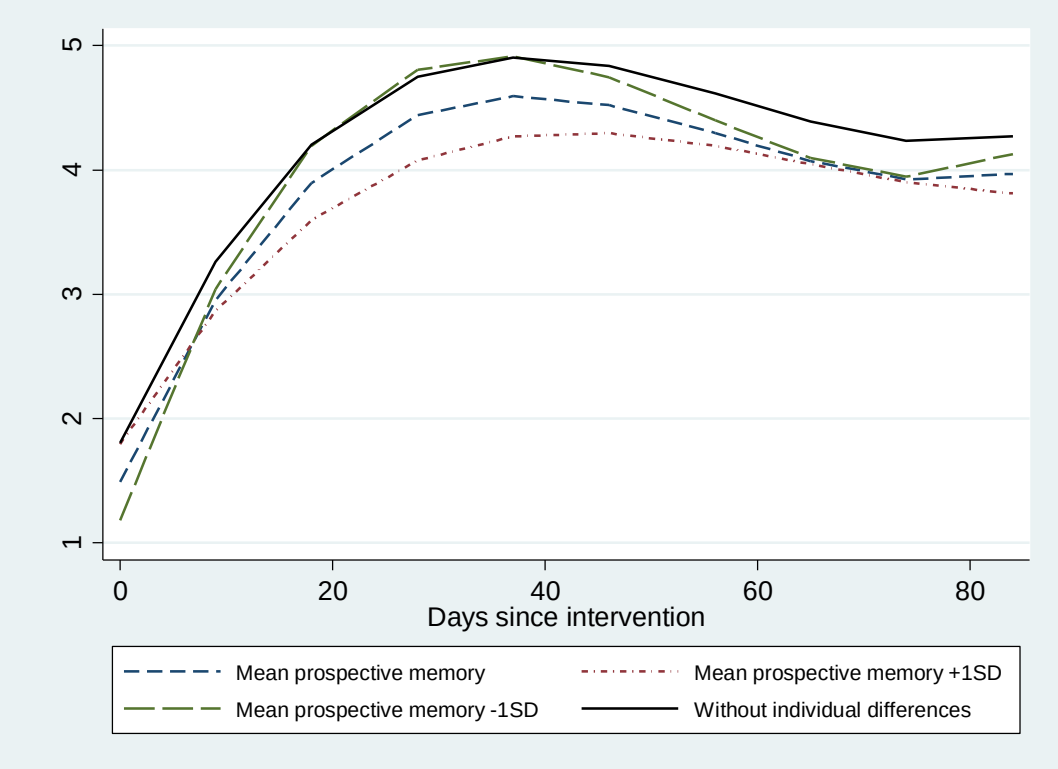

Figure 33 Comparison of predicted values of flossing behaviour with and without individual differences scores
All lines show values for a hypothetical participant, aged 40, with baseline reward scores of 4. Aside from the model without individual differences, the lines also show the effect of having an extraversion score of 6.07 (mean + 1SD)[19], and varying prospective memory scores.

5.4.5 Flossing Automaticity

Unadjusted associations between individual differences and flossing automaticity

Four of the ID variables were shown to have an effect on flossing automaticity when tested individually (see Table 30). PM had a significant negative effect with linear time, which indicates that the effect of PM on automaticity declines over time. Rational ability had a negative effect on flossing automaticity (b=-0.381, p=.029). There was also a negative effect of rational engagement on automaticity (b=-0.518, p=.002). Another new significant effect was observed for PNS (b=0.287, p=.013), whereby higher need for structure was associated with higher levels of flossing automaticity.

[19] The graphs are plotted with individual difference scores one standard deviation from the mean. This was to ensure that the predicted lines have less overlap with the plot not including individual difference scores, so that any differences in trajectories can more easily be distinguished. For the variable of prospective memory, which varies over time, the practice of plotting lines for the mean plus/minus one standard deviation, means that approximately two thirds of participants have values within this range.

Individual difference variable	Main effect		Interaction with timegroup, when found	
	B	p	Time variables	p
Prospective Memory	0.047	.757	Linear (B=-0.007)	.017
Rational Engagement	-0.518*	.002		
Rational Ability	-0.381*	.029		
Experiential Engagement	-0.209	.319		
Experiential Ability	0.035	.862		
Personal Need for Structure	0.288*	.013		
Emotional Stability	0.023	.790		
Conscientiousness	0.041	.636		
Agreeableness	-0.033	.754		
Extraversion	-0.060	.470		

Table 30 Parameter estimates for inclusion of each individual difference model separately within the regression for flossing automaticity

Adjusted associations between individual differences and flossing automaticity

Predictor	Regression of flossing automaticity			
	B	SE	p	Wald test, p
Intercept	1.561	0.831	0.063	
Time pre-intervention	0.017	0.006	0.003	
Timegroup post intervention				<.001
Time	0.117	0.017	<.001	
Time squared	-18.4~	4.73~	<.001	
Time cubed	0.11~	0.036~	0.003	
Baseline descriptive norm	0.223	0.087	0.011	
Baseline reward	0.389	0.090	<.001	
Rational engagement	-0.520	0.162	0.002	
Prospective memory	0.053	0.149	0.724	
Interaction Prospective memory * Time	-0.007	0.003	0.017	

Table 31 Final regression model for flossing automaticity, including significant individual difference variables
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

The final regression model predicting flossing automaticity, including all significant individual difference variables is shown in Table 31. Rational ability and personal need for structure, which were significant when tested in isolation, did not remain in the final model, when all individual difference variables are included. PNS was removed from the model by the backwards elimination procedure using the Wald test, with a significance level of p=.057. The positive effect of rational engagement remained (b=-0.520, p<.001). As before, there was a significant interaction between prospective memory and time (b=-0.007, p=.017, linear time only) but no significant main effect (p=.724). This significant interaction term is examined by considering Figure 34.

The line not including individual differences had an intercept higher than those including individual differences as a higher score for rational engagement was used, which predicts lower automaticity scores. When the individual differences scores are included, it appears that the peak automaticity occurs at an earlier time following the intervention. As high scores for prospective memory denote poorer PM ability, it can be seen that poorer PM was associated with a lower peak automaticity score. In addition, those with poorer PM ability showed a subsequent decline in automaticity, which was not observed for participants with good prospective memory ability. While there were no differences immediately after the intervention, higher prospective memory ability appeared to lead to higher habit scores being attained, as well as protecting against subsequent declines in automaticity. When considered in conjunction with the findings for flossing behaviour this is unsurprising. The attainment of higher levels of flossing behaviour seemed to lead to later increases in automaticity, suggesting that the effect of prospective memory on automaticity was likely to be mediated by behaviour. What may be unexpected is that despite flossing behaviour rates being observed to decline so that later there were no differences between those with different levels of prospective memory, the same did not occur for flossing automaticity. Rather, the predicted differences in flossing automaticity between those with differing levels of prospective memory was seen to continue to increase, even following the point when identical levels of behaviour were observed. It may therefore be the case that automaticity is predicted by the highest levels of behaviour frequency reached, as opposed to the current frequency levels. An increase of prospective memory ability of two standard deviations was seen to predict final automaticity scores approximately three quarters of a point higher.

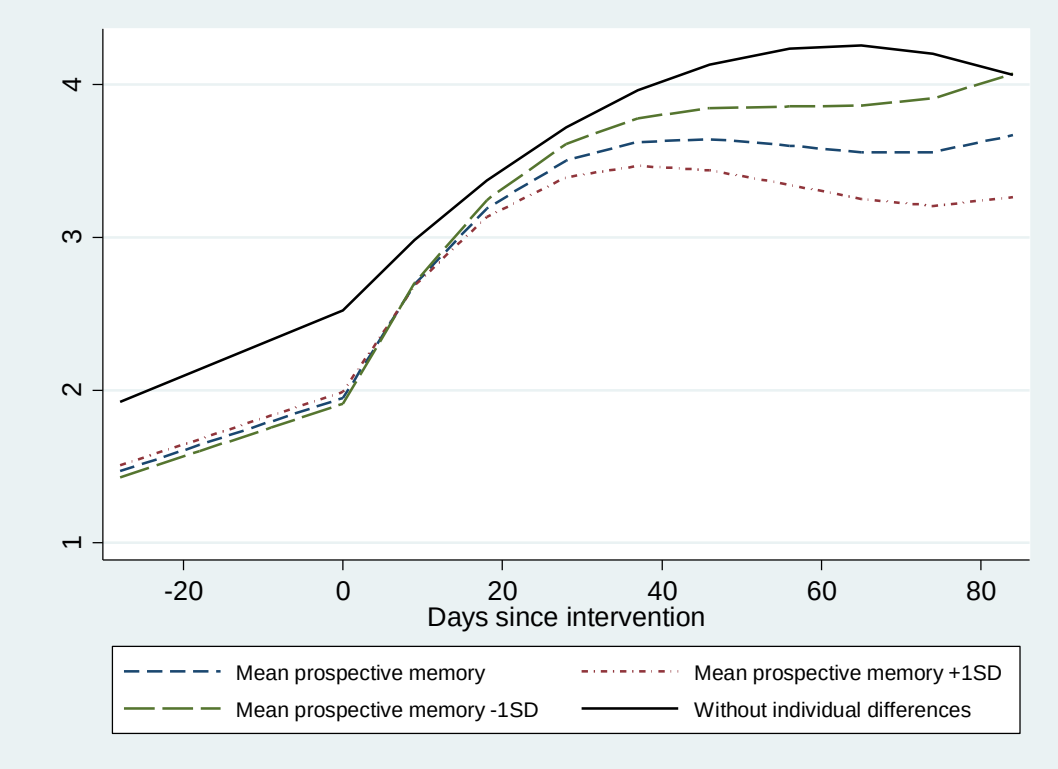

Figure 34 Comparison of predicted values of flossing automaticity with and without individual differences scores All lines show values for a participant aged 40, with baseline reward and descriptive norm scores of 4. Aside from the model without individual differences, the lines also show the effect of having a rational engagement score of 4.23 (mean + 1SD), and varying prospective memory scores.

5.4.6 Vitamin Behaviour

Unadjusted and adjusted associations between individual differences and vitamin behaviour

The parameter estimates for each ID variable when included individually in the vitamin behaviour model are shown in Table 32. None of the variables showed a significant interaction with time, so these were all excluded. As a result, the table only shows the estimates for main effects. None of the variables had an effect on behaviour. Likewise, when the variables were all included together in the full model, they were all excluded using backwards elimination with the Wald test, so that the final model was the same as that described in Chapter 4. Therefore, none of these ID factors had an impact upon the frequency of taking vitamin C tablets.

Individual difference variable	B	p
Prospective Memory	-0.437	.228
Rational Engagement	-0.218	.557
Rational Ability	-0.380	.331
Experiential Engagement	0.384	.423
Experiential Ability	0.289	.529
Personal Need for Structure	0.208	.396
Emotional Stability	0.148	.432
Conscientiousness	-0.195	.370
Agreeableness	-0.245	.268
Extraversion	-0.144	.432

Table 32 Parameter estimates for inclusion of each individual difference model separately within the regression for vitamin C behaviour

5.4.7 Vitamin Automaticity

Unadjusted associations between individual differences and vitamin automaticity

The parameter estimates for the ID variables when added individually to the vitamin automaticity regression are shown in Table 33. This included the effect of the interaction with the time variables where this had a significant Wald test. The effect of emotional stability on automaticity changed over time, including both linear and quadratic time (p=.038). (The nature of this changing effect over time is explored in the graph adjusting for all other individual differences, in Figure 35.) The main effect was marginally significant (p=.055), indicating that increases in emotional stability scores are associated with higher levels of automaticity. No other effects were observed, except one of rational ability which reached significance at the p=0.1 level (b=-0.475, p=.094).

Individual difference variable	Main effect		Interaction with timegroup	
	B	p	Time variables	p
Prospective Memory	-0.004	.988		
Rational Engagement	-0.161	.543		
Rational Ability	-0.475	.094		
Experiential Engagement	0.294	.396		
Experiential Ability	0.339	.315		
Personal Need for Structure	-0.030	.872		
Emotional Stability	.361	.055	Linear and quadratic	.038
Conscientiousness	-0.212	.162		
Agreeableness	-0.197	.221		
Extraversion	0.062	.640		

Table 33 Parameter estimates for inclusion of each individual difference model separately within the regression for vitamin C automaticity

Adjusted associations between individual differences and vitamin automaticity

The final regression model of vitamin C automaticity, including all significant ID variables, is shown in Table 34. Rational ability predicted lower levels of vitamin C automaticity (b=-0.817, p=.012). This implies that higher rational ability was associated with lower levels of automaticity. Experiential ability was associated with higher levels of automaticity (b=0.766, p=0.042). Emotional stability predicted higher levels of automaticity (b=0.388, p=.048) at the end of the study. However, the effect of emotional stability was also seen to change over time, including both a linear and quadratic component (examined in Figure 35).

Figure 35 illustrates the change in predicted values of vitamin C automaticity from adding in individual differences scores. (A range of scores is only plotted for emotional stability, as this is the only variable which was seen to have a varying effect over time.) Higher scores for rational ability were associated with lower automaticity scores, and higher scores for emotional ability were associated with higher automaticity scores. The effect of variation in emotional stability on automaticity was observed following the attainment of peak automaticity. Those with lower emotional stability scores showed a much greater decrease in automaticity scores following the peak. Emotional stability scores one standard deviation above the mean were associated with only a very small decline in automaticity following the peak scores, but scores one standard deviation below the mean were associated with a much greater decline in automaticity.

Predictor	Regression of vitamin C automaticity			
	B	SE	p	Wald test, p
Intercept	-1.595	1.657	0.338	
Time group				<.001
Adj time	-0.024	0.021	0.265	
Adj time squared	6.21~	2.75~	0.025	
Adj time cubed	0.078~	0.014~	<.001	
Age	0.035	0.016	0.036	
Baseline reward	0.471	0.182	0.012	
Rational ability	-0.817	0.311	0.011	
Experiential ability	0.766	0.370	0.042	
Emotional stability	0.388	0.192	0.048	
Emotional stability * Adjusted time				0.035
Emotional stability * Adjusted time	0.010~	0.004~	0.015	
Emotional stability * Adjusted time cubed	0.67~	0.37~	0.072	

Table 34 Final regression model for vitamin C automaticity, including significant individual difference variables
~ Values multiplied by 10,000, as quadratic and cubic effects have very small parameter estimates.

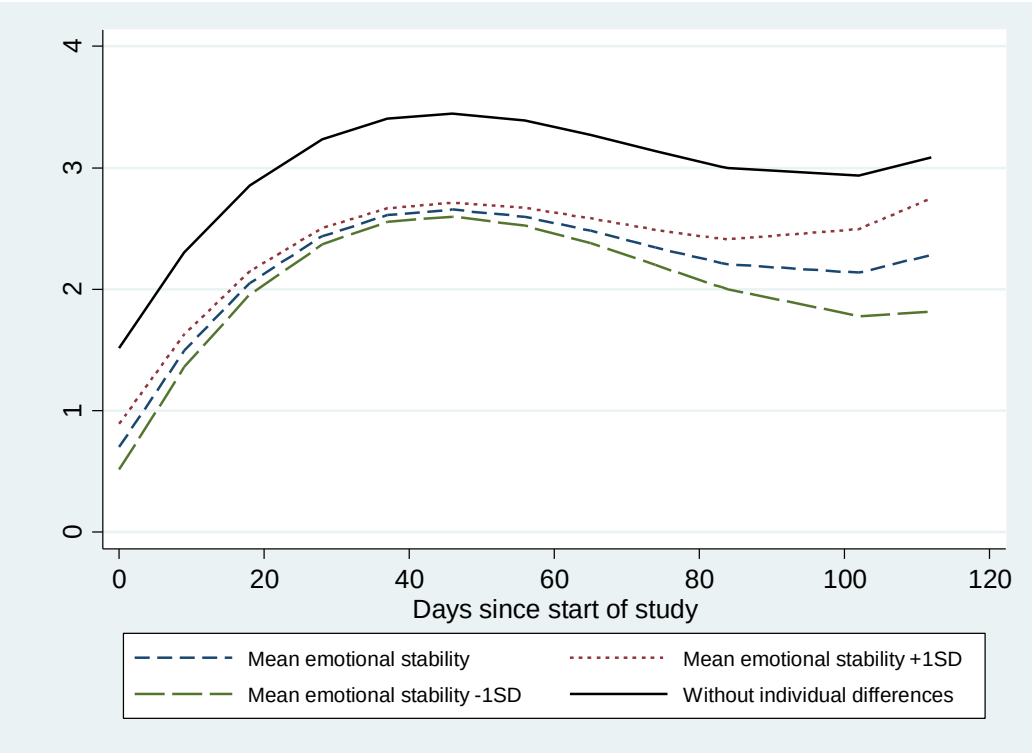

Figure 35 Comparison of predicted values of vitamin C automaticity with and without individual differences scores All lines show values for a hypothetical participant, aged 40, with baseline pleasure scores of 4. Aside from the model without individual differences, the lines also show the effect of having rational ability scores of 4.38 (mean + 1SD) and experiential ability scores of 2.99 (mean – 1SD), and varying emotional stability scores.

5.4.8 Hypothesis assessment

The hypothesis that better prospective memory ability will be associated with higher initiation rates of a new behaviour is supported with regards to flossing, but not for vitamin C (where there was no effect on behaviour or automaticity). The benefit of better prospective memory on flossing behaviour was seen only at the start of the study, and did not extend to predicting better maintenance. Despite no effect on behaviour maintenance, poorer prospective memory ability was seen to be associated with lower peak levels of automaticity, and also with a decrease in flossing automaticity after the initial peak is reached. The effect of prospective memory on automaticity appears to be mediated by the initial effect on behaviour.

Extraversion was associated with lower frequency of flossing behaviour (but had no effect on vitamin C). Emotional stability was associated with higher vitamin C automaticity (but had no effect on flossing). The effect of emotional stability on automaticity also changed over time, such that those with low emotional stability showed declines in automaticity after the peak level was reached. Therefore, while there is some evidence that personality traits are related to the likelihood of initiating and maintaining a new behaviour, these were inconsistent between behaviours, and weak, therefore resulting in poor support for hypothesis 6.

Hypothesis 7 anticipated an advantage for people with high need for structure on behaviour initiation and maintenance, which would lead to stronger habits. An effect on need for structure on flossing automaticity was observed, but it was not mediated by higher levels of behaviour. This effect was only found when the variables were considered in isolation: personal need for structure had no effect on behaviour or automaticity, when other ID variables were taken into account. No effect on vitamin C was found. There is therefore only partial support for this hypothesis, and the effect of need for structure appears to be on automaticity, without being mediated by higher levels of behaviour.

The hypothesis that experiential as opposed to rational thinking style will be associated with a tendency to stronger habits was supported across both behaviours.

5.5 Discussion

5.5.1 Summary

The effects of individual difference variables on behaviour maintenance and automaticity gain were investigated in this chapter. The factors investigated were prospective memory ability, Big 5 personality constructs, personal need for structure, and rational or experiential thinking style. Each of these classes of trait variables was observed to have an effect on either behaviour or automaticity for at least one of the target behaviours. No individual difference variables were observed to have any impact on the frequency of taking vitamin C tablets.

5.5.2 Effect of prospective memory

No effect of prospective memory was found on vitamin C behaviour or automaticity. For flossing, better prospective memory ability was observed to have a beneficial effect on behaviour initiation. Those with better prospective memory showed a faster increase in flossing behaviour immediately following the intervention, and reached higher peak levels of behaviour. However, following the peak in behaviour, levels then fell until there was no difference between those with different prospective memory ability. The observation that prospective memory ability predicts the initiation of a new behaviour is consistent with theory of prospective memory as performance of delayed intentions (McDaniel & Einstein, 2000). In a study of exercise behaviour following patient discharge from a rehabilitation centre, action control was seen to predict exercise behaviour six weeks later (Sniehotta, Nagy, Scholz, & Schwarzer, 2006), suggesting that this feature is important in the first weeks of behaviour change. As action control has been described as a predictor of acting on delayed intentions (Ellis & Kvavilashvili, 2000), this finding is consistent with the present results. The fact that initial advantages of higher behaviour levels following the intervention lead to higher peak behavioural frequency can be understood as performance of a behaviour leads to increased accessibility so it is less likely to be forgotten in the future (Tobias, 2009).

Prospective memory was also seen to have an effect on the development on habit, whereby those with high ability reached higher peak levels of automaticity, which did not show a subsequent decline over time. These findings can be understood when considered in conjunction with the effect of prospective memory on behaviour. As higher levels of behaviour are reached for those with high ability, the greater levels of flossing repetition

would result in more automaticity gain (Lally & Gardner, 2013). Therefore, the effect of prospective memory on habit is likely to be mediated by its effect on behaviour. These patterns can also be understood with reference to a study which modelled recycling behaviour over time (Tobias, 2009). Rather than prospective memory, this study investigated the effects of reminders, which may be seen as an external cue, rather than the internal cue from good prospective memory ability. However, as both reminders and prospective memory ability concern the prompting of behaviour that might otherwise be forgotten, the findings of that study may be relevant to the present research. The effects of reminders declined over time in that study, which is consistent with the initial benefit of high prospective memory waning over time in the present work. This decline in behaviour was protected against if the behaviour became automatic prior to the declining effect of the reminder on behaviour (Tobias, 2009). Therefore, the increased levels of behaviour frequency reached in the present study by those with high prospective memory ability may explain the higher levels of automaticity reached by those participants.

The observed effect of prospective memory on behaviour is also consistent with a previous study on flossing habit formation (Judah et al., 2012). In that study, a significant effect of prospective memory on behaviour was observed, but not on automaticity. As that study only lasted for four weeks, it appears that it detected the initial advantage conferred on behaviour levels by higher prospective memory ability, but did not last long enough to detect the subsequent advantage on automaticity as found in the present work, as this only started to become apparent in the present study approximately 30 days following the intervention. This is therefore longer than the monitoring period in the earlier study.

5.5.3 Effect of personality

With the notable exceptions of extraversion and emotional stability, personality variables tended not to affect either behaviour or automaticity, though one of the Big 5 variables (openness to experience) was not included in the analysis due to an unreliable measure. Where personality did have an impact, findings were inconsistent across the two target behaviours. Higher extraversion was associated with lower levels of flossing behaviour (though there was no effect on vitamin C behaviour). Higher emotional stability was associated with both higher levels of vitamin automaticity, and less decline in automaticity following attainment of the peak level (yet there was no effect on flossing automaticity). These findings are the opposite of the expected directions from past studies, of high

extraversion and neuroticism correlating with higher levels of behaviours that can be assumed to be habitual, including smoking, chewing gum and compulsive buying (Bivens et al., 2013; Malouff et al., 2006; Smith, Dauz, Clements, Werkowitch, & Whitman, 2009), plus extraversion is related to higher levels of physical activity (Gert-Jan De Bruijn, Kremers, Van Mechelen, & Brug, 2005). However, different types of behaviours may be predicted by different personality variables, or different levels of the same personality variables. Other studies of personality and dental health care have been mixed, with some showing that extraversion is associated with higher dental hygiene behaviour (Kressin, Iii, Bossé, & Garcia, 1999), and others showing worse dental hygiene practices in extraverts (von Knorring, von Knorring, Mörnstad, & Nordlund, 1987).

There appears to be conflicting evidence about whether the traits of extraversion and neuroticism are associated with positive or negative health behaviour. For example, extraversion has been associated with more frequent health behaviour, such as exercising, healthy diet and dental hygiene (Booth-Kewley & Vickers, 1994; Kressin et al., 1999), yet also with risky behaviour such as sunbathing (Leary, Tchividijian, & Kraxberger, 1994). Similarly, neuroticism has been reported to be associated both with less performance of risky behaviours such as smoking and risky sexual behaviour (Vollrath, Knoch, & Cassano, 1999), but also with more unhealthy behaviour such as smoking, or not brushing teeth or exercising, (Kressin et al., 1999; Vollrath et al., 1999). The lack of any clear pattern in the literature, plus the lack of consistency between findings for the two target behaviours in the present study, suggests that personality may not be a fruitful area of research in the habit formation field, and so future investigation of this relationship is not advised.

5.5.4 Effect of personal need for structure

Personal need for structure was observed to have a positive effect on flossing automaticity when considered in isolation, but not when other individual difference variables were included. (No effect was observed for vitamin C.) This may be because it was seen to be negatively correlated with rational engagement, which remained in the final combined model as a predictor of poorer automaticity, and so the effect of the need for structure variable may have been explained by the greater effect of rational engagement. However, the fact that it was observed within the individual model still shows that preference for a more structured and predictable lifestyle is weakly associated with greater habits.

Personal need for structure has been observed to correlate with having an ordered routine (Reich & Williams, 2003), therefore, high scores on need for structure may be associated with having greater stability in the context of daily life. This would be expected to result in greater automaticity due to more frequent and consistent pairings between behavioural cues and responses. No effect of need for structure on behaviour was detected, indicating that the effect on automaticity is not because having a more structured life facilitates adoption of a new behaviour, which subsequently leads to automaticity. Rather the effect of having a more structured life is likely to impact upon automaticity regardless of behaviour levels. This empirically demonstrates the contribution of context-dependent repetition to habit formation (Lally & Gardner, 2013; Lally et al., 2010). Interestingly, a previous empirical investigation between the need for structure measure and habits found no association (Wood et al., 2002). The present study found a main effect, but no interaction term which in this case means that it had the same beneficial effect on automaticity throughout the study, from the point of the intervention, to the final level of habit reached, as opposed to one observed to change over time during the habit formation process. Therefore, it may have been expected that an effect of this variable would also have been detected in the study on existing habits by Wood. However, that study utilised a different measure of habit, based on behavioural frequency and context stability, rather than measuring the degree of automaticity, which is considered to be the defining feature of habit (Gardner, 2012). This different in conceptualisation of habit may have resulted in the discrepancies between the null effect observed previously (Wood et al., 2002) and the observed effect of need for structure in the present study.

5.5.5 Effect of thinking style

High rational ability scores predicted lower flossing behaviour in the model adjusted for other individual difference variables. High rational engagement also predicted low flossing automaticity, but not when other individual difference variables were also taken into account. For vitamin C, high rational ability predicted lower levels of automaticity, in contrast to experiential ability which predicted higher levels of automaticity. As rational ability and engagement, and experiential ability and engagement are highly correlated, the findings suggest a positive effect of experiential thinking of habits, and a negative effect of rational thinking on habits.

These findings are comparable to the observation that need for cognition is negatively associated with current habits in students (Wood et al., 2002). A study of doctors' thinking

style and hand hygiene compliance reported a positive association between behaviour and experiential thinking style, but no association with rational thinking style (Sladek et al., 2008). The association between experiential thinking style and habits was observed in the present study for the behaviour of taking vitamin C tablets only. In addition, the negative effect of rational ability observed here across both behaviours, but not observed in the study on hand hygiene, can be understood here as rational thinking style utilises a contrasting process to experiential thinking, therefore a positive effect of one may be expected to imply a negative effect of the other. In addition, the present study measured the effect on habit, rather than just behaviour, and therefore stronger outcomes may be expected due to the explicit parallel between habitual behaviour and dual process models (Wood et al., 2014).

There is limited further evidence on the effect of these different thinking styles on behaviour. However, rational and experiential thinking style has been observed to correlate with types of response given in a task with either a reasoned or heuristic response option (with responses seen to associate with rational or experiential style respectively), and experiential style is found to be associated with faster response times (Witteman, van den Bercken, Claes, & Godoy, 2009). In addition, there is evidence of a double dissociation in that habit moderates the effect of implicit attitudes on behaviour, whereas need for cognition moderates the effect of explicit attitudes on the established behaviour of sweet consumption (Conner, Perugini, O'Gorman, Ayres, & Prestwich, 2007). That study did not find a correlation between need for cognition and habit. Yet it looked at correlates of existing behaviour, rather than the process of habit formation investigated in the current work.

The finding that explicit attitudes are more predictive of behaviour for those with higher need for cognition (Conner et al., 2007) confirms the claim that thinking style affects the relative effectiveness of implicit (unconscious or automatic) versus explicit (slow and cognitive) effects on behaviour.

5.5.6 Comparison between behaviours

Different individual difference variables were observed to have significant effects on the behaviours of flossing versus taking vitamin C tablets. It is important to note that the sample size for vitamin C tablets was a third lower than that for flossing, which may explain some of the differences in results. The most common difference in the results between the two target behaviours was that a variable was observed to have a significant effect for flossing, but not for taking vitamin C. This supports the expectation that the lack of significant effects for

certain variables on vitamin C behaviour and automaticity, is likely to be due to a lack of power to detect some effects that were present for the behaviour of flossing. It would therefore be interesting to conduct further research into the effect of individual differences on habit formation, but with a larger sample size.

Extraversion was seen to have a negative effect on flossing behaviour, and emotional stability a positive effect on vitamin C automaticity. The inconsistency in findings between the two behaviours, and lack of support from the existing literature suggests that these findings are not of great importance. Personal need for structure had a positive effect on flossing automaticity, only when other individual difference variables were not taken into account. As only a weak association was found here, it is not surprising that an effect was not found with vitamin C tablets, as the sample size may not have been sufficient to test this weak effect. Further research could shed more light on this relationship, which is theoretically expected to be important for habit formation.

Prospective memory was only observed to have an effect on flossing behaviour and automaticity, not on vitamin taking. This pattern is surprising, as in the semi-structured interviews at the conclusion of the study, many participants said that if they remembered to take the vitamin C tablets, then they would always do so, therefore the primary reason for not taking the tablets was forgetting. In contrast to this, many participants said that while they sometimes forgot to floss, on occasion they remembered, but did not do so, as they "could not be bothered", or were "too tired". Other participants said that the reason they did not floss was never due to forgetting. This implies that if a significant effect is observed for flossing, it may be likely for taking vitamin C tablets as well, and therefore this may have been detected with a larger sample size. However, this cannot be confirmed from this study.

Thinking style was the individual difference variable with the greatest similarity between the effects observed on the two behaviours. For both flossing and vitamin C, high rational thinking was associated with lower automaticity, and rational thinking was also associated with lower levels of flossing behaviour. Experiential preference was associated with higher vitamin C habit. The assertion that rational as opposed to experiential thinking style may have a detrimental effect on habit formation across different behaviours was therefore well supported by the data.

5.5.7 Conclusions

The findings support the claim that the habit formation process is affected by measures of individual differences. Varying degrees of support was found for the different traits. Need for structure was weakly associated with stronger habits and prospective memory was associated with better initiation and automaticity gain. The finding that was best supported was the advantage of experiential rather than rational thinking style on habits. The findings support the consideration of interventions targeted according to people's individual traits, so that support may be given at the point of the habit formation process in which they may need it most. This is discussed in more depth in the discussion chapter.

Chapter 6: Discussion

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6.1 Study overview

This study aimed to investigate potential predictors of habit formation beyond context-dependent repetition. Greater understanding of habit formation would have the benefit of informing interventions which are more likely to lead to sustained behaviour change, potentially through the identification of ways to promote increased automaticity per behavioural repetition. Factors investigated included: placement of the new behaviour within a routine; interventions focussed on attraction motivation versus health; types of

psychological variables which may serve as rewards to reinforce behaviour; and the effect of individual difference variables on the habit formation process.

The study tracked self-reported behaviour and automaticity (along with measures of motivation and reward) over the course of sixteen weeks, for the target behaviours of flossing and taking a vitamin C tablet. An intervention for vitamin C tablets was delivered at the start of the study, and an intervention for flossing after four weeks. A two by two design was employed within the flossing intervention, whereby participants were randomised to interventions based on attraction or health, and to receive instructions to floss before or after brushing. The effects of potentially rewarding features were investigated within the behaviour of vitamin C, using a correlational design. The conclusions from the hypothesis testing will be outlined. General patterns and implications of the findings from the results chapters will also be elaborated upon here.

6.2 Results of hypothesis testing

6.2.1 Effect of placement in a routine on flossing behaviour and automaticity

It was anticipated that flossing after rather than before brushing would lead to greater levels of flossing behaviour and automaticity. This was due to predictions from Event Segmentation Theory (Zacks & Swallow, 2007). Memory is seen to be disrupted over the boundary between different events, or chunks of activities in a routine (Speer & Zacks, 2005; Swallow et al., 2009). Therefore cues selected at an event boundary (as is expected to be the case when participants floss before brushing) may be less likely to lead to changes in behaviour. Furthermore, the increased brain processing observed at event boundaries (Fujii & Graybiel, 2003; Ruh et al., 2005; Speer et al., 2007) may suggest that a behaviour at this point is less likely to become automatic. A tendency for flossing after brushing to lead to greater automaticity has been observed in past research (Judah et al., 2012). However, the present research saw no difference in levels of flossing behaviour or automaticity between those flossing before or after brushing, and therefore, the hypothesis was not supported. The study was powered to test this hypothesis according to the expectation of a medium sized effect. However, the lack even of a trend to an advantage of flossing after rather than before brushing, suggests that only being powered to detect a medium effect was unlikely to be the reason why no effect was detected.

This may be understood with reference to alternative implications suggested from findings in the routine literature. In contrast to the hypothesis of the present study, the increased awareness observed at the point of event boundaries has been predicted to increase the chance that behaviour can be successfully inserted at this point (Lally & Gardner, 2013). It may be the case that the tendencies of memory disruption, and increased control and flexibility associated with event boundaries, may conflict with one another, resulting in the observed finding of no overall advantage for flossing either before or after brushing. In addition, it is possible that the assumption on which the hypothesis relies is false: that the same processes act when processing one's own behaviour, as when observing the behaviour of others. This may not be the case (Jones & Nisbett, 1971; Malle et al., 2007), which would result in Event Segmentation Theory not being expected to have an effect on individual routine behaviour.

6.2.2 Effect of flossing interventions based on attraction versus health

It was hypothesised that interventions based on attraction would be more likely to lead to behaviour change and automaticity than interventions based on health. This expectation was based on evidence that knowledge of health benefits or risks often does not lead to changes in behaviour (Curtis et al., 2011; Danaei et al., 2009), and that emotional drivers are a better predictor of behaviour (Aunger & Curtis, 2013; Curtis & Aunger, 2011). However, no differences were observed in the rates of flossing behaviour or automaticity between the groups who received the intervention focussed on attractiveness or health. While the study was only powered to detect a medium effect of differences between groups, it was also observed that the two interventions did not have lasting effects on the corresponding attractiveness or health motivation scores. The change in attraction motivation following the intervention did not differ between intervention groups. The group who received the health intervention only showed significantly greater increases in health belief up to four weeks following the health intervention. Therefore, the interventions did not appear to have the intended effect on the target motivations, and while it is possible, the lack of a significant effect appears unlikely to be due to a lack of power.

The interventions may have failed to have the desired effect on the relevant motivations as they were simple interventions based on leaflets, delivered at one timepoint only. The leaflets may have been an insufficiently strong medium, to have a significant and lasting effect on a specific type of motivation, as opposed to just affecting motivation for flossing in general. Usually, tests of interventions investigate the effect of one type of intervention compared to a

basic control condition. The fact that two otherwise-matched interventions were being tested for their effects on behaviour and automaticity via different motivations, meant that the sample size may have been insufficient to detect this type of subtle effect. The failure of the interventions to have differential effects on motivations, meant that they would not be expected to have differential effects on the pre-cursors of behaviour such as intention, on behaviour, or on subsequent automaticity (Lally & Gardner, 2013).

While the interventions did not change motivation as intended, the impact of beliefs about the effects of attractiveness or health motivation on flossing behaviour and automaticity, was also investigated. However, no effect of either motivation was observed, suggesting that contrary to the expectations, the motivation of attractiveness was not more likely to lead to flossing behaviour or automaticity than beliefs about health. Past research has found that factors such as socioeconomic status, smoking, and frequency of brushing affect whether teenagers are motivated perform dental hygiene behaviours for reasons of achieving good dental health, or being more attractive (Macgregor et al., 1997). Therefore, the finding that individuals may differ in their motivations to dental hygiene behaviour suggests that one type of motivation may be unlikely to be more effective than another in changing behaviour across a sample. The lack of a distinction between the effects of expected attraction or health outcomes on flossing behaviour can also be understood in light of the fact that habitual behaviours are characterised by a lack of reliance on goals (de Wit & Dickinson, 2009; Neal et al., 2012; Wood & Neal, 2009), and therefore, beliefs about outcomes (such as attraction or health) would be expected to have little impact upon habits.

6.2.3 Effect of reward on automaticity

The effect of perceived rewards on automaticity was investigated in both target behaviours of flossing and taking vitamin C tablets. It was expected that reward would strengthen the relationship between behaviour and automaticity (de Wit & Dickinson, 2009), due to reinforcement strengthening the association between the context and the behavioural response. Within the behaviour of taking vitamin C tablets, the effects of different potentially rewarding variables were investigated.

Effects of different potentially rewarding variables

The data suggests that pleasure and intrinsic motivation act as rewards by moderating the behaviour-automaticity relationship, whereas general attitude or specific expectations about the outcome of the behaviour, did not have a significant effect on either behaviour or automaticity. It therefore appears that features inherent in the performance of the behaviour are found to be rewarding, whereas aspects of the consequences of performing the behaviour are not.

For flossing, the reward variable combined questions about whether the behaviour was satisfying, and experiential attitude (whether the behaviour is pleasurable to do). This variable was also observed to predict greater automaticity gain. The reward variable investigated for flossing was analogous to the reward-as-pleasure variable for taking vitamin C tablets. This aspect of reward as pleasure can be seen as similar to that used in animal studies, which typically uses food such as sucrose solution, which has an immediate hedonic benefit (Adams, 1982; Broadbent et al., 2007; Faure et al., 2005; Yin & Knowlton, 2006). This comparison between human and animal habit formation is not surprising, as habit is an evolutionarily old system (Aunger & Curtis, 2008), and is associated with comparable brain areas in humans and animals (Balleine & O'Doherty, 2009). It has been observed in past research that affective valence (good/bad feelings), during ten minutes of physical activity, was predictive of levels of physical activity after six months (Williams, Dunsiger, Jennings, & Marcus, 2012). Affective valence can be thought of as being comparable to pleasure, and so the effects of this on physical activity maintenance can be considered comparable to the habit formation results observed in the present work. The impact of pleasure on habit formation observed in the present work suggests that the experience of performing the behaviour itself is an important predictor of maintenance and automaticity.

The other variable seen to act as a reward in this way for vitamin C was intrinsic motivation. While there is some overlap in questions between this and the pleasure variable, intrinsic motivation can be seen more broadly as how much a participant is motivated by internal reasons to perform the behaviour (Markland & Tobin, 2004; Ryan & Deci, 2000). The results of the present study show that behaving in a way consistent with intrinsic motivation is rewarding and leads to automaticity gain. This finding is consistent with past research of existing habits which has shown a relationship between intrinsic motivation and automaticity (Gardner & Lally, 2013; Wiedemann et al., 2014).

The variables observed not to act as rewards were those measuring features of the outcome: general attitude about whether the behaviour is beneficial or not; and more specific expectations about perceived benefits of the behaviour. Despite there also being some conceptual overlap between intrinsic motivation and general attitudes, the latter was not found to act as a reward. These attitude variables did not have an effect on either behaviour or automaticity. It is possible that the lack of a significant effect was due to a lack of power. However, the parameter estimates observed were not in line with a trend to an effect which did not reach significance. In addition, the finding that beliefs about the outcome of the behaviour are unimportant for forming a vitamin C habit, is consistent with the finding that motivations of attraction and health did not have a significant effect on flossing automaticity, as these variables measured the expected outcome of flossing. Likewise, there was no effect of the variable measuring the perceived relative effectiveness of flossing over brushing alone. There is additional confidence in the findings of no effect of variables related to flossing attitudes compared to vitamin C attitudes, as the sample size was fifty percent larger, suggesting that the null effect for attitudes on vitamin C habit formation was probably not due to lack of power. The fact that there was consistency across both behaviours, that beliefs related to the expected outcomes, or the value of the behaviour, had no impact upon automaticity, suggests that factors not related to the experience of performing the behaviour itself are unlikely to reinforce behaviour and lead to automaticity gain.

The belief variables can also be understood as being related to goals, as they concern the outcomes of the behaviour. The finding that these did not impact upon habit formation relates to habit theory by providing additional evidence against the view that habit is automatic goal-directed action (Aarts & Dijksterhuis, 2000; Bargh & Chartrand, 1999; Danner et al., 2011). As outcome goals are observed here to be unimportant when learning a habit, they are unlikely to become important once a habit is already established.

Effect of reward on automaticity

Finding a behaviour rewarding was observed to predict automaticity for both flossing and taking vitamin C tablets. This was either via a direct effect on automaticity, or by moderating the behaviour-automaticity relationship. While the moderating effect was not observed at every time point, there is some support for the hypothesis that reward strengthens the effect of behaviour repetition on automaticity. The finding of both a direct and moderated effect of reward provides evidence against models that suggest rewards only have an impact upon

automaticity that is mediated by behaviour (Lally & Gardner, 2013; Wood & Neal, 2009). The results support the notion from the animal learning literature that rewards reinforce behaviour, making it more likely to become habitual (Adams, 1982; Dickinson, Balleine, Watt, Gonzalez, & Boakes, 1995; Holland, 2004). This observed moderation effect provides the important experimental evidence that rewards strengthen the relationship between behaviour and automaticity in human habit formation. This is consistent with studies of existing habits in humans, whereby intrinsically motivated participants had a stronger relationship between behavioural frequency and subsequent habit strength for fruit consumption (Wiedemann et al., 2014), and physical activity (Gardner & Lally, 2013).

However, direct effects of reward on automaticity, not mediated or moderated by behaviour, were also observed in the present study. A similar direct effect was also detected in a study of existing physical activity habits (Gardner & Lally, 2013), as well as in a study of flossing habit formation (Judah et al., 2012), although the latter study did not look for moderated or mediated effects, so these cannot be ruled out. The direct effect of reward on automaticity, independent of behaviour, is not expected by standard theories for humans or other animals. As discussed in more detail below, this may be an artefact of measurement error, or may also indicate that there could be other intermediate variables on the pathway between reward and automaticity which were not measured.

In considering the timeframe following the intervention in which the effects of rewards were seen, there does seem to be a broad level of consistency between the reward types and behaviours. For flossing, experienced rewards showed a direct effect and an effect mediated by behaviour four weeks following the intervention, a moderation of the behaviour-automaticity relationship eight weeks following the intervention, and a direct effect on automaticity twelve weeks following the intervention. For vitamins, the effect of pleasure on automaticity was only via moderation of the behaviour-automaticity relationship, and was seen eight and twelve weeks following the intervention. For intrinsic motivation, moderation of the behaviour-automaticity relationship was seen four and eight weeks following the intervention, as well as a direct effect on automaticity sixteen weeks following the intervention. Therefore, the general trend observed across reward types was that increased reward strengthened the relationship between behaviour and automaticity around eight weeks following the intervention, with additional effects either earlier or later than this.

Contrary to this, it is expected that rewards should have an effect soon after behaviour initiation, before behaviour has become automatic (Wood and Neal 2009). For example, in consumer behaviour, rewards such as a loyalty program, or a free item, only had an effect on customers with low rather than high current rates of purchase (Lal & Bell, 2003; Liu, 2007;

Taylor & Neslin, 2005). Consistent with this, work on reinforcement learning in monkeys has shown that rewards trigger responses in dopamine neurons during the task learning phase, but not once performance is established (Ljungberg, Apicella, & Schultz, 1992; Mirenowicz & Schultz, 1994). Intrinsic motivation for vitamin C, and experienced reward for flossing did have an impact upon automaticity in the first measurement point four weeks following the intervention. However, the fact that this early effect was not seen for pleasure, and that the effects of reward persisted after this point, once habit levels were observed to have plateaued, is not consistent with the expectations from the literature (Wood & Neal, 2009). It may be the case that the behaviours in this study did not become sufficiently strong habits to no longer be sensitive to rewarding outcomes.

However, one important distinction between the earlier studies and the present research is that they investigated extrinsic rewards, whereas the current study only measures features that are intrinsically rewarding. Extrinsic rewards may rely on behaviour being driven by goals, in order for the reward or incentive to impact upon behaviour, with the result that they have less of an impact upon behaviours which have become habitual and therefore less sensitive to current goals. However, the intrinsic rewards tested here are not related to the outcome of the behaviour, but are rather inherent in the experience of performing the activity itself. Therefore, it may be the case that while extrinsic rewards only have an impact before habits are formed, the effectiveness of intrinsic rewards may continue later in the habit formation process. The fact that intrinsic motivation is seen to strengthen the relationship between behaviour and automaticity for existing habits (Gardner & Lally, 2013; Wiedemann et al., 2014), supports the assertion that the impact of intrinsic rewards on automaticity may continue beyond the behaviour initiation phase.

In support of this claim, other theories of habit formation also allow an effect of reward beyond the learning period. For example, the description of the habit system within the Associative Cybernetic model (de Wit & Dickinson, 2009), states that a reward experienced while a stimulus-response connection is activated, strengthens that connection regardless of whether the habit has formed or not. This is in line with the reinforcement process described by Thorndike's Law of Effect, whereby a rewarding outcome strengthens the connection between the stimulus and response, making the outcome more likely to be repeated (Thorndike, 1911). Therefore, the findings of the present study support the notion that rewards may impact upon habit learning at any point in the process. This should not be seen as a criticism of the claims arising from the literature on consumer behaviour, animal learning, or neuroscience, that rewards only have an effect early in the habit formation process, but rather as a caveat that the findings from extrinsic rewards observed in those literatures may

not generalise to intrinsic rewards. The suggestion that intrinsic and extrinsic rewards may promote habit formation and affect existing habits in different ways is not surprising given the distinctions between the effect of intrinsic and extrinsic motivation on behaviour (Ryan & Deci, 2000).

6.2.4 Effects of individual differences

Summary

Individual difference variables were seen to impact upon flossing behaviour and automaticity and vitamin C automaticity, but no effects were found on vitamin C behaviour. In line with expectations, rational thinking style was negatively associated with habits, and this was the only variable with a consistent effect across both behaviours. Personal need for structure was associated with higher automaticity, and prospective memory with higher flossing initiation and subsequent automaticity. However, these effects were observed for flossing only, as opposed to vitamin C. This may be due to the fact that the sample size for vitamin C was one third smaller than it was for flossing, therefore it is anticipated that there was not enough power to detect these effects.

The results confirm that easily measureable individual difference variables can be used to help predict habit strength, or the process of habit formation. That the findings are largely consistent with expectations, suggests that the theoretical foundation in which each individual difference variable is based can reasonably be applied to studies of habit formation.

Effect of prospective memory

For flossing, better prospective memory ability led to faster rates of initiation of a new behaviour, and higher peak behaviour levels, though there was no difference in behaviour rates by the end of the study. The more frequent initial behaviour for those with high prospective memory likely resulted in the higher levels of automaticity observed by the end of the study. Therefore, the hypothesis about the effect of prospective memory was supported for the behaviour of flossing, but not taking vitamin C tablets (where no effect was observed).

The impact of prospective memory on immediate behaviour initiation is expected theoretically (McDaniel & Einstein, 2000). There is also empirical support for the effect of prospective

memory on behaviour over the course of a few weeks following initiation (Judah et al., 2012; Sniehotta et al., 2006), which then later declines in importance as habits form (Tobias, 2009). While greater automaticity would be expected as a consequence of greater levels of behaviour performance (Lally & Gardner, 2013), the present study may be the first to demonstrate this effect as a result of individual differences in prospective memory ability. The findings demonstrate the importance of prospective memory ability not only for behaviour initiation, but also for automaticity gain. This suggests that prospective memory ability may have long-term effects on behaviour maintenance. Therefore, it may be useful for habit research to refer more closely to the literature on prospective memory, in order to advise further research, and to consider the prospective memory ability of individuals in habit formation attempts.

Effect of personality

While personality variables were observed to have some effects, these were inconsistent across the two behaviours. However, the expectation that personality affects the habit formation process had less theoretical support than the other individual difference variables. Extraversion had a negative effect on flossing behaviour, and emotional stability had a positive effect on vitamin automaticity. While some effect of personality on behaviour and habit was in line with the hypothesis, the directions of these observed results were the opposite of what was anticipated (Bivens et al., 2013; Malouff et al., 2006; Smith et al., 2009). However, the unexpected findings, and the inconsistency of results between the two behaviours is comparable with the conflicting reports of the effects of personality variables on behaviour (Booth-Kewley & Vickers, 1994; Leary et al., 1994; Montag & Levin, 1990; Vingerhoets, Croon, Jeninga, & Menges, 1990; Vollrath et al., 1999). This suggests that any findings from personality research in habits and habit formation may not generalise across behaviours and settings. For this reason, any findings on personality are unlikely to assist further development of habit theory, or to inform general principles for intervention design. Therefore, further research on personality in the field of habit formation may not be a useful endeavour, and is not recommended.

Effect of personal need for structure

Personal need for structure was expected to have a beneficial effect on behaviour. While no effect on behaviour was observed, high need for structure was weakly associated with greater

flossing automaticity. This trait was not found to have an effect in a study on existing habits (Wood et al., 2002), though this may be due to the different measurement of habit used, which did not assess automaticity, or due to the correlational design which investigated existing habits. As this variable is related to stability of daily routines (Reich & Williams, 2003), the finding is consistent with the importance of context-dependent repetition on habit formation (Lally & Gardner, 2013; Lally et al., 2010). This variable may be a useful indicator when predicting habits or habit formation, as it is unlikely that all relevant aspects of context can be identified or measured. Therefore, a variable indicating the stability of a person's routine may provide a proxy for unmeasurable contextual cues to habits.

It is surprising that need for structure did not also have an effect on behaviour, as it was expected that effects of this variable on automaticity would be mediated by behaviour. However, as there was only a weak effect on automaticity, it is possible that there was not enough power to fully investigate all effects of this variable. In addition, this may be the reason why there was not a significant interaction effect seen with time, which is what would have been expected if need for structure were to have an effect only after the new behaviour had been initiated, as the repeated performance in a regular structure gradually leads to stronger habits.

Effect of thinking style

The hypothesis about the effect of thinking style on automaticity was the most well supported of those on individual differences. However, rather than a supportive effect of experiential style on automaticity, it was rather a detrimental effect of rational thinking style on automaticity that was most dominant. This was observed both for flossing and vitamin automaticity. Preference for rational thinking style also predicted lower levels of flossing behaviour, and high experiential thinking style predicted stronger vitamin C automaticity. The findings are consistent with a study on existing habits (Wood et al., 2002), and on hand hygiene compliance in doctors, although here an effect was seen of experiential style only, as opposed to a negative effect of rational style (Sladek et al., 2008).

Rational and experiential thinking style relate to the reflective and automatic systems in dual process models (Pacini & Epstein, 1999). Therefore, the observed impact of thinking style on habit supports the comparison made between the dual-process model approach, and habit versus deliberative behaviour (Wood et al., 2014). This is therefore another literature which may usefully be consulted when developing hypotheses which could be tested in future habit

studies. For example, the fact that rational thinking style was associated with lower levels of automaticity, and experiential thinking style with higher levels of automaticity, may reflect a tendency for those with a preference for rational style to act in a deliberative and goal-directed rather, than a habitual way. Considering both deliberative, as well as automatic processes when studying habit formation may improve the predictive ability of our models.

6.3 Additional findings

6.3.1 Effect of intentions on behaviour and automaticity

It was expected from the literature that intentions would only be weakly predictive of behaviour (Sheeran, 2002; Webb & Sheeran, 2006). However the presented study observed even less effect of intention on behaviour than expected. Intention was only observed to be a predictor of flossing behaviour four and eight weeks following the intervention. Intention did not significantly predict behaviour for taking vitamin C tablets at any point in the study. Furthermore, these effects of intention were from measures taken concurrently for intention and behaviour. When the structural equation models for flossing were constructed using reward and intention variables measured four weeks prior to the behaviour and automaticity variables, intention was not observed to be a predictor of behaviour at any timepoint[20]. The difference between the effects of intention seen in the two model specifications for flossing is consistent with the claim that intentions are a better short term rather than long term predictor of behaviour (Sheeran, 2002; Verplanken, 2006), and should therefore be measured as close as possible in time to the opportunity to perform the intended behaviour. The combination of intention being a poor predictor of behaviour (even the limited effect of intention on flossing behaviour declined over time), with the significant effects of prior on current behaviour, further supports the expectation that past behaviour is a better predictor of future behaviour than intentions (Aldrich et al., 2010; Danner et al., 2008; Ouellette & Wood, 1998). The present findings therefore provide additional evidence that intention has at best a limited effect on behaviour for activities that may be habitual, and that intention may have less of an impact upon behaviour than typically assumed. However, it is also possible

[20] The analysis selected and presented was the version using intention and reward variables measured concurrently with behaviour and automaticity, as at least some relationship between intention and behaviour was theoretically expected. Therefore, a model showing this was assumed to be more appropriate. However, despite the use of concurrent measure, no effect of intention on behaviour was observed for the models predicting vitamin C behaviour and habit.

that the extremely limited effect observed of intention on behaviour was due to measurement error, probably in the measurement of behaviour.

Intention also moderated the behaviour-automaticity relationship whereby stronger intentions weakened the effect of behaviour on automaticity. This was observed at one timepoint only, both when modelling flossing and vitamin C automaticity. This effect was not expected, but may be understood as a logical consequence of the distinction between doing a behaviour intentionally and automatically. The automaticity measure includes questions assessing to what extent participants perform the behaviour without thinking, or without needing to consciously remember, which a way of acting that does not rely on strong intentions (Ouellette & Wood, 1998). This may explain why intention weakened the impact of behaviour on automaticity gain. However, one of the vitamin C models (four weeks following the intervention) showed a positive direct effect of intentions on automaticity, and this pathway was also observed to tend towards significance at other timepoints and in other models. This suggests that intention may have a beneficial effect on automaticity not mediated by other variables in the model. The simple slopes analysis of the moderation effect conducted in chapters three and four revealed that repetitions still promote automaticity; however, they have a smaller impact for strongly intended behaviours. This effect was seen in the models across both behaviours, and within the models for vitamin C including either pleasure or intrinsic motivation as the "reward" variable; however, each model showed this effect of intentions at different timepoints. Therefore, while the existence of this effect at some point in the habit formation process may be well supported, it does not appear possible to draw conclusions about the timing of this effect.

It is currently recognised in the literature that behavioural repetitions lead to habits, even if the behaviour occurs non-intentionally (Orbell & Verplanken, 2010). The present study extends this claim, to suggest that intentionally performed behaviours appear to have less impact on automaticity gain than those which are not strongly intended. It is known that increased perceived contingency between the behaviour and "rewards" reduces the speed at which habits form, both in the animal learning and neuroscience literature (Dickinson, 1985; Dickinson et al., 1983; Yin & Knowlton, 2006), and from research into consumer behaviour (Bell, Ho, & Tang, 1998; Fox & Semple, 2002; Kivetz et al., 2006; Wood & Neal, 2009). Therefore, a possible mechanism for the observed effect of intentions weakening the behaviour-automaticity relationship may be that when participants have strong intentions for a behaviour, the behavioural goals are more salient, thus increasing the perceived contingency between the behaviour and "rewards": this reduces the speed at which habits form. However,

as the finding was unexpected, further research should attempt to replicate this effect, as well as to explore potential mechanisms for the finding.

6.3.2 Effect of context stability on behaviour and automaticity

From the habit formation literature, context-dependent repetition is cited as the mechanism by which habits form (Lally & Gardner, 2013; Lally et al., 2010). However, the support for this claim from the present study varied between the two behaviours investigated. For the models of flossing automaticity subsequent to the intervention, the only effect of context stability on automaticity was mediated by behaviour. Therefore, the effect of context stability was only observed through increasing the likelihood of behaviour repetition, rather than it being a mechanism by which a behaviour becomes more automatic. However, the measurement of context in this study only assessed the placement of the behaviour within an existing routine and location in which the behaviour was performed. The context which can prompt a habit is likely to be made up of much broader cues than this, as any feature of the environment could contribute to a habitual process (Verplanken, 2005). For example, aspects such as other people, or visible objects in the environment, may cue a behaviour, but were not measured here. A broader measurement of context may have been more likely to find the expected effect. Nevertheless, when using context-dependent repetition as an intervention tool, it is likely that place and point in a routine (i.e. after a given action) will be the features of the context focussed on (Gardner, Lally, et al., 2012; McGowan et al., 2013; Orbell & Verplanken, 2010), yet the effect of these aspects was observed only to be through predicting behaviour repetition.

The importance of context-dependent repetition was better supported by the data on automaticity for taking a vitamin C tablet. At points soon after the intervention, performing the behaviour in a more stable location, and at a more consistent point in the routine, was found to strengthen the relationship between behaviour and automaticity. This is what would be expected by the theory of habits forming through context-dependent repetition, therefore it was surprising that this effect was not also observed for flossing. It may be the case that there was not a large amount of variation in potential context for flossing, as the behaviour tended to be performed in the bathroom, around the time of toothbrushing. This lack of variation would have reduced the ability of the context stability variable to explain variance in automaticity gain for flossing, compared to a behaviour with more potential variation in the situation of performance.

In any case, there is evidence to support the importance of context-dependent repetition in the formation of a vitamin C habit, particularly early on in the habit formation process. However, as the variables for reward were also seen to moderate the behaviour-automaticity relationship, it is clear that while context-dependent repetition is necessary in order for habits to form, it is not the sole proximal determinant of habit formation.

6.3.3 Effect of age

Another covariate which showed differences between the two behaviours was age. While the regression analysis for both behaviours included a positive effect of age on habit, only flossing retained this variable in the SEM analysis. For vitamin C tablets, age did not have a significant effect in any of the SEM models, and was therefore excluded. The regression analysis for flossing also showed that increasing age had a positive impact upon behaviour levels. This effect of age for flossing did not seem to be mediated by context stability. Age was associated with higher flossing habits at the start of the study, higher levels of automaticity and behaviour four weeks after the intervention, and higher levels of flossing behaviour at the end of the study, twelve weeks after the intervention.

The positive effect of age on flossing behaviour is consistent with the literature on older adults showing better performance on naturalistic (rather than abstract, lab based) prospective memory tasks compared to younger adults (Bailey, Henry, Rendell, Phillips, & Kliegel, 2010; Rendell & Craik, 2000). However, when considering the observed advantage for older age on automaticity gain, the findings seem contrary to the evidence that older adults are impaired on a stimulus-response (habit) learning task (Marschner et al., 2005; Mell et al., 2005). Yet, older adults are also found to be impaired in goal-directed learning (de Wit, van de Vijver, & Ridderinkhof, 2014). As goal-directed and stimulus response learning are opposing systems, the present finding that age confers benefits on habit formation may suggest that while both learning systems decline with age, the age-related decline may be less for habit (compared to goal-directed) learning, resulting in an overall tendency to more automaticity gain. More research would be needed in order to confirm this assertion.

6.4 Strengths of the study

6.4.1 Study of habit formation

The present research adds to the previously small number of studies studying features of the habit formation process (Judah et al., 2012; Lally et al., 2010; Tobias, 2009). Despite calls for habit formation to be promoted as a means to sustainable healthy behaviour change (Lally & Gardner, 2013; Rothman, 2000), the vast majority of research on habits investigates correlates of existing habits, rather than attempting to intervene to form new habits, or study the predictors of the habit formation process (Gardner, 2014).

Correlates of between-participant variation in existing habits are not necessarily predictors of habit formation. For example, there is evidence that predictors of behaviour can differ from predictors of behaviour change (Skår et al., 2008). The reliance on correlational studies, as well as prospective studies on ongoing behaviours, has been criticised as leading to biased estimates, and therefore being misleading regarding recommendations for intervention design (Weinstein, 2007). This is because the psychological correlates with behaviour (and by extension, habit) may have been the result of regular performance of behaviour, rather than the cause of the behaviour. For example, favourable perceptions may lead to behaviour and habit, but in addition, the performance of a behaviour may enhance favourable perceptions about that behaviour. This is more likely the case with frequently repeated behaviours and therefore those behaviours investigated in habit research. It is possible that motivations and beliefs tend to align with behaviour and habits, due to the tendency to reduce cognitive dissonance (Harmon-Jones & Mills, 1999), for example, for beliefs that may be inconsistent with a regularly performed unhealthy behaviour such as smoking. For these reasons, correlational studies may inflate the relationship between behaviour, and psychological perceptions such as reward, motivation or intention.

This overreliance of correlational designs in habit research has been criticised, and there has been a call for more experimental investigation of habits, in order to understand factors that promote automaticity (Sniehotta & Presseau, 2012). Aggregates of between-person differences cannot reliably be used to explain within-person effects (Molenaar, 2004). Therefore, as habit formation is an individual process, correlational studies of between-person variation in habit strength are not methodologically suitable for investigating habit formation. The present study takes multiple measurements during a formation attempt, and uses appropriate statistical techniques which estimate within person change, while controlling for

variation between individuals. This study therefore adds to the small number of existing studies of habit formation, and contributes to theory due to the demonstration of factors observed to predict the development of new habits.

6.4.2 Broad study population

Participants were members of the general public, living in and around London, with varying levels of occupation and household composition (couples, families etc). The population studied was therefore more generalizable to the national population (or Western populations in general), than the usual sample of undergraduate students often used in psychology research (Gallander Wintre, North, & Sugar, 2001; Peterson, 2001; Sears, 1986). This means that the findings are more likely to be generalizable for any subsequent health behaviour change interventions aimed at the general public in Western, developed countries. The fact that the behaviours were not self-selected is likely to mean that participants had lower levels of intrinsic motivation, and therefore lower likelihood of sustained behaviour change, than they might have done for self-chosen behaviours. This may also mean the findings have wider applicability, as behaviour change interventions in the real world may not always target people who have taken the prior decision to attempt to change the target behaviour (DiClemente & Prochaska, 1998; Zimmerman et al., 2000).

6.4.3 Long monitoring period

The study also monitored behaviour and automaticity over a relatively long time period of sixteen weeks (twelve weeks following the flossing intervention, and sixteen weeks following the vitamin C intervention). This is a benefit of the present study, as the length exceeds the median time taken to form habits in a study tracking the trajectory of habit formation over time (Lally et al., 2010), suggesting that many participants in the present study may have been expected to have reached their peak habit rates during the period of monitoring.

6.4.4 Effective intervention

For both flossing and taking vitamin C, the observed rates of behaviour over the course of the study were not predicted by the prior behavioural frequency of the participant. This suggests that both interventions were effective at changing behaviour regardless of the baseline rates. This is noteworthy considering they were both relatively simple interventions. The flossing intervention was more intensive as the face-to-face session included detailed discussion of the individual routine of the participant, as well as presentation of information from a leaflet about benefits of flossing, and instructions on how to floss, followed by guidance in the formation of an implementation intention. The vitamin C intervention was much simpler, as information about the benefits of the behaviour was just presented within an online questionnaire, followed by instructions on forming an implementation intention. The fact that both these interventions led to significant changes in behaviour suggests that simple motivational and volitional interventions can achieve behaviour change, and where supplemented with advice on habit formation, may lead to long-term behaviour.

6.5 Recommendations for practice

The findings from this experimental study of habit formation lead to some recommendations for behaviour change interventions aiming to form habits.

Firstly, the finding which leads most easily to practice is the effect that intrinsic motivation strengthens the effect of behaviour repetition on automaticity gain. One recommendation may be to target habit based interventions at individuals who are intrinsically motivated, or by encouraging people to make self-directed changes in behaviour. However, this is not always possible, so the finding that intrinsic motivation promotes habit formation can instead be applied more proactively, through designing interventions which aim to foster intrinsically motivated behaviour.

According to Self-Determination Theory, intrinsic motivation can be encouraged by working to boost autonomy, competence, and connection with others (Deci & Ryan, 2002; Ryan & Deci, 2000). For example, strategies such as self-recording of performance, and giving positive feedback can promote autonomy and competence to keep people intrinsically motivated (Baldwin et al., 2009; Michie et al., 2009). Intrinsic motivation can also be encouraged if the behaviour change attempt is supported by people to whom the participant can relate (Ryan &

Deci, 2000), such as non-professionals who have personal experiences related to the behaviour being changed (Abraham & Gardner, 2009; Wilkinson, Sniehotta, & Michie, 2011).

The other feature which strengthened the effect of behaviour repetitions on automaticity was pleasure. However, in terms of implications for health habit formation and intervention design, it may be hard to manipulate the pleasure experienced in performing a behaviour. Yet, it does suggest that the efforts made by manufacturers of products to make them more pleasurable to use may have an impact not only on behaviour, but also on automaticity. One suggestion for health psychologists may be that when designing or delivering behaviour change interventions, researchers should focus on the behaviour itself, and how people experience it. In so doing, focus can be placed on pleasurable aspects of the behaviour, and if a behaviour is not enjoyable to perform, then - where possible - strategies could be employed to reduce unpleasurable aspects.

While the evidence for the effect of context-dependent repetition on behaviour and automaticity was limited (particularly for the behaviour of flossing), there was some evidence that it was associated with behaviour frequency, and that it strengthened the behaviour-automaticity relationship for vitamin C. Therefore, as a predictor of sustained behaviour, if not automaticity, context consistency should still be encouraged in behaviour change interventions. Individuals should be encouraged to plan when and where they will do the target behaviour, and to try to prompt the behaviour performance with another appropriate activity. This prior-action cue should both take place at the same location as the target behaviour, and with the same frequency as the intended target behaviour in order to reliably and consistently prompt performance. The format of implementation intentions was observed to be an effective way of ensuring this planning in the present study. The findings from the vitamin C intervention showed that a simple online intervention including guidance in forming an implementation intention was able to achieve lasting behaviour change. This type of intervention is scalable where resources do not allow more intensive contact with a behaviour-change implementer. However, an online intervention could be further developed to become more interactive in a way recommended by Self Determination Theory, through including facilities to enable self-monitoring, and to provide feedback and encouragement, in order to promote intrinsic motivation.

This study demonstrated that measureable individual difference traits can explain variability in behaviour and habits. This may suggest that certain types of people are more appropriate targets for habit formation interventions. Alternatively, interventions could possibly be targeted to an individual following assessment of their traits, such that additional support could be provided in a way that a participant may need it most. For example, if the weak

effects observed for personal need for structure are replicated in a future study, those who have lower scores on this index could be supported in developing more routine regularity around the target behaviour, or through additional contextual cues or reminders. Alternatively, efforts could be made to identify the areas in their life of greatest structure, and to try to anchor the new target behaviour to that point.

The detrimental effect of poor prospective memory ability on the behaviour frequency levels achieved, and on subsequent automaticity, suggests that reaching lower levels of behaviour early on after initiation of a new behaviour may have lasting implications for the strengths of habits formed. It is already known that implementation intentions can facilitate tasks requiring the performance of delayed intentions (Chasteen, Park, & Schwarz, 2001), yet this is a behaviour change strategy which is often used already. To supplement the effects of implementation intentions, those who have poor prospective memory ability could be assisted in the initiation phase with visible reminders (Tobias, 2009) or text messages.

The disadvantage of the preference for rational thinking on automaticity (and potentially behaviour) does not appear to be as easy to modify; however, if it is recognised that people high on this trait may not form habits as easily and that behaviour is therefore likely to remain under more intentional control, then efforts could be focused to keep motivation and remembering high for the target behaviour, through booster sessions ever few weeks or months.

6.6 Limitations

6.6.1 Behaviour monitoring equipment

The design of the study to accommodate the sensor system led to various limitations. Due to the requirement of participants to wear a wrist sensor, and have sensors installed in their bathroom for sixteen weeks, (in addition to requiring low baseline rates of the target behaviours) recruitment was challenging. Many different avenues were pursued in attempting to recruit participants, however these did not yield results. Therefore, the services of a professional market research recruiter were used to recruit participants. However, the use of a market research recruiter meant that some participants reported at the end of the study that they were “doing the behaviour because they thought they had to”. This was despite the researcher clearly stating that participants were only being asked to try to perform the

behaviours. There was also the possibility that the monitoring equipment served as a visible reminder to perform the behaviour. For flossing, 68% participants stated at the end of the study that the sensors made them "definitely, probably or possibly" floss more often than they would have done otherwise. For vitamin C tablets, this figure was 56%. However, even though these numbers are already relatively high, it is important to acknowledge that the equipment may have had a further impact on behaviour, outside the awareness of participants. For all these reasons, the study may not have been as naturalistic as hoped, as there may have been unintended factors promoting behaviour performance beyond a typical behaviour change intervention. However, the alternative of behavioural self-report can also lead to behaviour reactivity due to the beneficial effect of self-monitoring on behaviour change (Dombrowski et al., 2010; Michie et al., 2009; Suresh et al., 2012).

There was not complete consistency of researcher contact between participants and households, as beyond the three experimenter visits, some households required extra visits to fix equipment problems, which could not be fixed. Some participants also did not complete their questionnaires, and so were sent email or text reminders, or where these did not prompt response, some participants received phone calls asking them to complete the questionnaires. These factors are likely to have led to differential reminder effects between participants.

As the study was intensive to execute, in order to include sufficient participants, all recruited households had to have at least two participants who were willing to take part. This introduced clustering to the data. However, this was taken into account in the regression analyses. Furthermore, to enable investigation of many hypotheses as part of this study, participants received interventions on two different behaviours. Multiple behaviour change is seen to be more complicated than just intervening on different behaviours separately (Nigg, Allegrante, & Ory, 2002; Noar, Chabot, & Zimmerman, 2008; Sweet & Fortier, 2010) and there is the possibility that the different behaviours would interact, or compete for self-control (Muraven & Baumeister, 2000). The vitamin and flossing interventions were conducted at different sessions, four weeks apart, partly to avoid potential conflict from two behaviours being initiated at the same time. The behaviours were also not self-selected, which may have had implications for the intrinsic motivation to perform the behaviours. However, this was explicitly measured for the behaviour of taking vitamin C tablets. (The fact that the behaviours were not self-selected may have resulted in natural variation in intrinsic motivation, which would have been advantageous given that the effects of this variable were being tested.) Another restriction from the use of sensors was that participants had to keep the vitamin bottle in the bathroom, and were encouraged to take the tablet there too. At final interview, some participants said that they would typically take medication or supplements in the

kitchen, so this may have led to the behaviour being performed in a way that felt unnatural for some participants.

6.6.2 Main self-report study limitations

One potential source of improvement to the study could have been the use of more objective measures of habit, as opposed to self-report. Self-report measures of habit have been criticised, as the extent to which people can consciously report on their subconscious action has been doubted (Hagger, Rebar, Mullan, Lipp, & Chatzisarantis, 2014; Nisbett & Wilson, 1977; Sniehotta & Presseau, 2012). However, there is some evidence that people can be aware of the tendency to do something automatically (Gardner, Abraham, et al., 2012a; Gillan et al., 2014; Lally, Wardle, & Gardner, 2011). For example, a qualitative study of participants following a habit formation intervention demonstrated that participants experienced the behaviour as requiring decreasing amounts of effort and forethought, and that they became more automatic over time (Lally et al., 2011). In addition, there is evidence from a lab based study that actual habitual responses are associated with a subjective urge to respond (Gillan et al., 2014), suggesting that self-report measures of habit may be valid.

There have also been questions raised about the ability of participants to properly comprehend questions about automaticity, given results from a think aloud study (Gardner & Tang, 2014). Problems experienced by participants in that study included a lack of confidence in reporting on automaticity, and misinterpretation of items. Problems were only reported on 10% of responses; however, that study used a student sample, which may be expected to find these questions easier to answer than the general-public sample used in the present study, which was likely to have had a larger range of years in formal education. Therefore, the present study may have had a greater level of problems due to participants not interpreting the questions as intended. The issue of informant comprehension of questions has also been raised following a think-aloud study of Theory of Planned Behaviour variables for the behaviours of binge drinking and physical activity (French, Cooke, Mclean, Williams, & Sutton, 2007). The study found problems including difficulty in retrieving information, and answering questions in ways not intended by the researchers. This may suggest that some of the reward and motivation items were also challenging to answer, or inaccurate measurements of the underlying constructs.

As raised in the think-aloud study (Gardner & Tang, 2014) and elsewhere (Maddux, 1997) another potential discrepancy between participants when answering questions from the SRBAI

is whether the questions are understood to be asking about the automaticity of initiating a behaviour (i.e. the learned triggers to action), or the automaticity in executing the behaviour (i.e. the chain of actions required in performance of the behaviour) (Gardner, 2014). The intended focus here was on initiation, given that automaticity is being understood as relating to the likelihood that a behaviour will be performed. However, it is possible that some participants understood the questions to be related to execution, as it was observed that some participants reported high scores for habits at baseline, despite reporting current rates of behaviour near zero. This appears illogical, unless it is acknowledged that participants may be reporting on the automaticity of the sequence of events they perform on the rare occasions that they do take a vitamin tablet. It is therefore possible that some participants may have either had difficulties in interpreting the questions, or not interpreted the questions in the way intended. The combination of these measurement issues suggests that the use of a self-report measure of habit, and other psychological variables, may have introduced measurement error which violates the assumptions of the structural equation models used, and therefore may result in the findings being less reliable.

An alternative to the use of self-report measures of habit is reaction-time or task response based measures. These may be seen as being more objective measures of automaticity than self-report, as if a behaviour is performed in a more automatic way, it should be more quickly activated, or made accessible on presentation of the relevant cue as a prime (Aarts & Dijksterhuis, 2000). One example is the Response Frequency Measure (Verplanken, Aarts, van Knippenberg, & van Knippenberg, 1994), which measures the frequency of travel type responses given rapidly to different presented location goals. However, this is not easily generalizable to different behaviours, and also assumes a view of habit as goal dependent, as opposed to cued by contextual stimuli. Measures can also be based on the Implicit Association Test, by comparing reaction times when congruent pairs of behavioural cues and responses are presented as opposed to control or incongruent pairs (de Bruijn, Keer, Conner, & Rhodes, 2011). Another type of task would combine a lexical decision task with subliminal priming to assess associations between a behavioural response, and different cues or control words through comparison of reaction times (Neal et al., 2012). The disadvantage of these measures is that they are sensitive to the selection of the appropriate cue, which may vary between participants. Therefore, the necessity to elicit individual cues for the task provides an additional difficulty to administration of the measure (Neal et al., 2012). Furthermore, measures based on reaction times cannot be easily administered online as opposed to in a lab, as the measurement of reaction times would be dependent on the speed of the browser being used.

6.6.3 Analysis limitations

The sample size was constrained by the number of sets of equipment that could be purchased. While this sample was sufficient according to the sample size calculation (powered to detect differences between two intervention groups), and interesting significant differences were detected, a larger sample could have added confidence in the results. Furthermore, due to the complex yet exploratory analysis for the remaining hypotheses, the required sample size could not be calculated for these, therefore null findings may potentially have been due to lack of power. Yet, despite the potential of there being insufficient power, interesting results were observed that were also consistent between the two behaviours.

As a result of the large number of hypotheses, many investigations were performed on one relatively small dataset. This may have increased the likelihood of spurious results. However, as continuous variables were tested in the Structural Equation Models, this results in greater power, and more robust findings. The findings from the SEM models rely on the assumptions that the model is correct, that there is no measurement error, and that there is no unmeasured confounding. These are strong assumptions. The model specification was based upon theoretical and empirical expectations, and showed relatively good fit to the data, which raises confidence that the assumption of the model being correct is not violated. The possibility for unmeasured confounding cannot be discounted, nor can the assumption that there is no measurement error. In particular, there may be measurement error due to self-report measures of both automaticity and behaviour, rather than reaction time measures of automaticity, or the sensor-recorded measures of behaviour. In particular, it is possible that the theoretically unexpected direct effect between rewarding variables and automaticity was due to the violation of the latter two assumptions. For example, unmeasured confounding on the pathway between reward and automaticity may mean that although a direct effect was detected here, there is actually another variable which mediates this effect, but which was not measured. Future studies could consider the possibility of other potential mediators on the pathway between reward and automaticity.

However, many of the positive results are in line with the hypotheses or expectations from the literature. Furthermore, the main finding of the existence of variables that serve as rewards by increasing the effect of repetitions on automaticity gain, was observed for both flossing and vitamin behaviours. The timing of this was also relatively consistent between behaviours, as it

was seen around eight weeks following the intervention. This consistency, and the detection of observed effects, adds confidence in the validity of the findings.

6.7 Future research directions

This study highlights a number of future research directions to further develop theory of human habit formation, and to test and demonstrate its utility in health behaviour change.

Firstly, it would be important to see whether the findings about the properties of perceived rewards, and the factors that work in this way, are also observed across different behaviours. Different behaviours may vary in the extent to which they are pleasurable to perform, or the beneficial outcomes of the behaviours may be more or less apparent following performance. Demonstration of these findings across a range of behaviours would support the generalizability of the results of the present study. Furthermore, in order to test the utility of these findings to the challenge of behaviour change, they would need to be developed and tested as part of interventions. This would require investigating whether interventions aimed to increase intrinsic motivation, or pleasure, can actually work to positively change those variables, and also to strengthen the relationship between behaviour repetitions and automaticity gain in the manner observed here. For example, intrinsic motivation can be encouraged through supporting self-directed changes where possible as opposed to directing people to follow external instructions, or through positive feedback (Baldwin et al., 2009; Michie et al., 2009), or supporting competence (Ryan & Deci, 2000).

It should be noted that the question regarding the effects of pleasure was originally intended to be investigated in this study. Initially one of the target behaviours was handwashing with soap after going to the toilet, however this intervention was discontinued due to ceiling rates of handwashing habits at baseline, resulting in no scope to change habits with the study. The investigation of handwashing habit formation was going to test the hypothesis that having soap that is more luxurious and therefore more pleasurable to use, will strengthen the relationship between behaviour repetition and automaticity gain. This question should be investigated again, using a target behaviour where there is more scope to increase behaviour and habits. Additional studies could also further investigate additional factors which may act as rewards in promoting habit formation, and the mechanism by which they work. The effect of pleasure as a reward, which is consistent with that seen with in animal studies, suggests that the literature on habit learning in animals may be used to provide testable hypotheses for habit research in humans.

Effects of prospective memory and personal need for structure were observed for flossing, but not vitamin C, which had a smaller sample size. Further research should attempt to replicate this effect in additional behaviours and with a larger sample. In addition, the findings for thinking style were not completely consistent across the two behaviours, so this should also be researched in greater depth to understand the nature of the effect of thinking style on behaviour and automaticity. The impact of tailoring interventions to provide additional support to overcome likely barriers, should be investigated for its effect upon habit formation for individuals with trait dispositions suggesting difficulties in forming strong habits.

As it is probable that formation studies of real-world habits will continue to use self-report measures of habit, it would be highly beneficial for these measures to be validated against more objective reaction-time measures of automaticity, such as a version of an Implicit Association Task, or priming studies. (In order to make these comparable, the same context stem should be used in the questionnaire measure as the prime in the reaction time measure. This leads to the challenge of needing different versions of the test for different individuals according to the context in which they perform the behaviour.) If the measures are observed to be comparable, then confidence can be gained in the use of the SRBAI in habit studies. If the measures are not comparable, then efforts should be made to institute the use of reaction time measures in habit research, and to develop versions that are standardised and can be used easily by social psychology researchers. However, it has been claimed that no measure, either self-report or reaction-time based, can ever really measure habit, as decision tasks which may be used as comparisons have also been criticised (Blanton et al., 2009; Fiedler, Messner, & Bluemke, 2006; Friese, Hofmann, & Schmitt, 2009), and so convergent validity is not sufficient (Hagger et al., 2014). Yet this seems a fatalistic view – while no measure is perfect, the concept of habit is a useful one for behaviour change, and is characterised by a number of properties which may be tested against the available measures. If high correlations were to be found between different imperfect yet contrasting measures, this would increase the likelihood that they may be valid. Therefore, work can be done to further assess the existing measures, and to improve the accuracy of the measures used, so that they can better approximate the underlying habit strength.

One caution in this field, particularly if findings are to be generalised outside the experimental context, is that the measurement of intentions or cognitions has an impact on the behavioural outcome (Godin, Bélanger-Gravel, Amireault, Vohl, & Pérusse, 2011; Morwitz & Fitzsimons, 2004). This phenomenon is often termed the mere-measurement-effect. Therefore, efforts should be made to reduce the amount of monitoring used in both behaviour change and habit formation studies. (Alternatively, if unobtrusive, objective monitoring tools are used, studies

should include a pre-intervention monitoring period in which participants can become accustomed to being monitored, so that initial reactivity in behaviour as a result of being monitored would have reduced by the time of the habit formation attempt.) Where there is extensive monitoring, it could usefully be tested as part of an intervention to compare rates against participants with less frequent behaviour reporting.

Many participants mentioned that seeing the equipment was a visible reminder which was important at the beginning of the study, but this had less impact later on. While this work focussed extensively on factors which promote automaticity gain, there would be a benefit to understanding how to extend the performance of behaviour following intervention, to increase the likelihood of frequent performance of the behaviour continuing for long enough for the behaviour to become habitual (Tobias, 2009). Future work could investigate different types of reminders, such as visible reminders or text messages, or the effectiveness of booster interventions to sustain behaviour and the timings of boosters that may be most effective.

6.8 Conclusions

Certain features, such as finding a behaviour pleasurable, or being intrinsically motivated, appear to accelerate the habit formation process, leading to greater gains in automaticity for a given level of behaviour repetition. This suggests that interventions should consider the rewarding nature of the behaviour, and attempt to foster intrinsic motivation. Further research could also investigate other potential aspects of reward in human habit formation. There was also some evidence that individual differences – namely, experiential as opposed to rational thinking style, prospective memory ability, and personal need for structure – were associated with forming stronger habits. These findings suggest that certain people may be better suited to habit formation attempts, or that interventions should be targeted to support individuals at points in the habit formation process that are likely to be more challenging for them. This work clearly demonstrates the importance of factors beyond repetition in predicting the strength of habits and likelihood for habit formation. Therefore, future work may usefully investigate other potential factors which may further develop habit theory.

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Appendix 1 Flossing intervention

The pages of the leaflet are presented below in the following order:

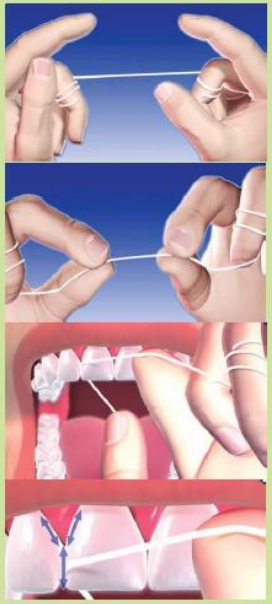
Attraction leaflet – outside

Attraction leaflet (After toothbrushing group) – inside

Health leaflet – outside

Health leaflet (Before toothbrushing group) - inside

How to floss



1. Wrap the ends of a 45 cm (18 inch) section of floss around your middle fingers. Most of the floss should be wrapped around one finger, and as the floss is used, the other finger takes it up.

2. Hold the floss between your thumbs and forefingers. Leave one or two inches of floss between them. Use a fresh section of floss for each tooth.

3. Gently work the floss between your teeth using a zig zag motion. Don't snap the floss between your teeth. When you reach the gumline, curve into a "C" shape around the tooth, making sure to go below the gumline.

4. Gently glide the floss up and down several times between each tooth, including the back surface of your last molar. Remove the floss from between each tooth using the same zig zag motion.

Your gums may bleed when you start to floss... this is a sign you REALLY need to be flossing as you have an infection. Bleeding should stop after you have been flossing every day for about a week.

The smile is rated the most attractive physical feature

Keep yours looking its best with daily flossing

Why flossing is a good idea

Smile with confidence. Flossing makes your teeth look brighter and whiter, by removing plaque and staining from food and drink. A survey of 1000 people found that people rated pictures of a person as looking younger if they had whiter teeth.

Banish bad breath. Bad breath is more common than many people realize – often people have it without being aware there is a problem. Flossing daily is one of the easiest ways to avoid bad breath.

When to floss

Flossing gives the best results in the evening before bed. Because this is when you have less saliva, and the conditions are best for bacteria to grow and form dental plaque.

The prevention and removal of dental plaque can keep your teeth fresh till next morning when you brush your teeth.

Flossing may carry bacteria and food particles below the gum line, so it is better to **floss after brushing** to reduce the foreign matter that can be transferred below the gum line by the floss.

Brushing alone is not enough.

In a recent study researchers told people to either brush their teeth twice a day for two weeks, or brush and floss.

Only the flossing group showed a significant improvement in bad breath, and their teeth were visibly whiter.

"I didn't think I would want to keep flossing, but it really makes me feel more confident: my teeth look nicer and my breath is better."

The flossing pledge

My flossing reminder

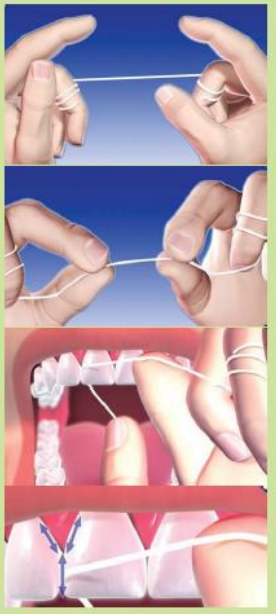
_____

_____

I pledge to floss every night after brushing

Signed: Date:

How to floss



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4. Gently glide the floss up and down several times between each tooth, including the back surface of your last molar. Remove the floss from between each tooth using the same zig zag motion.

Your gums may bleed when you start to floss... this is a sign you REALLY need to be flossing as you have an infection. Bleeding should stop after you have been flossing every day for about a week.

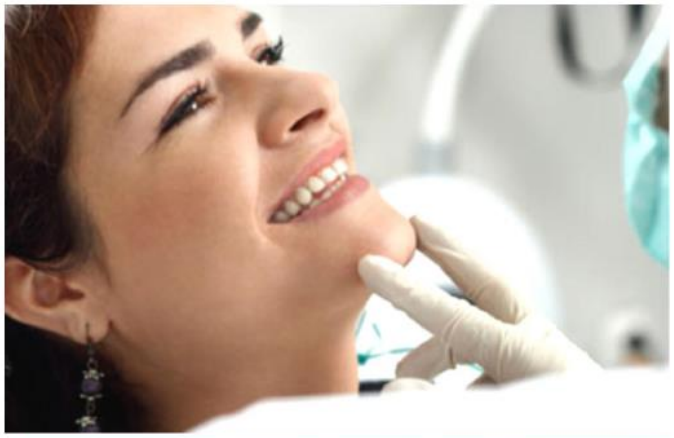
Dentists recommend flossing daily for healthy teeth and gums

Why flossing is good for dental health

Flossing cleans where the toothbrush can't reach Daily flossing disturbs bacteria between your teeth and stops it before it can create plaque and cause **gum disease** and **dental cavities**.

Gums might swell and bleed easily in the earliest stage of gum disease, but a**t its worst,** you might lose your teeth. **93% of people** in the UK will suffer from gum disease at some point in their lives. Flossing can help prevent it.

Other health effects There's increasing evidence linking periodontal disease to an increased risk of heart disease.



When to floss

Flossing gives the best results in the night time before bed. Because this is when you have less saliva, and the conditions are best for bacteria to grow and form dental plaque.

The prevention and removal of dental plaque can keep your teeth fresh till next morning when you brush your teeth.

Flossing before brushing removes what has been dislodged from between your teeth by the floss, and also allows fluoride from the toothpaste to reach between the teeth.

Brushing is not enough to fight gum disease.

In a recent study researchers told people to either brush their teeth twice a day for two weeks, or brush and floss.

Only the flossing group showed a significant improvement in gum bleeding, which is a sign of an increased risk of severe gum disease.

The flossing group had 38% fewer bleeding gum sites than before the intervention.

"I didn't realize I had gum disease until I started flossing – I can tell my teeth and gums are much healthier now."

The flossing pledge

My flossing reminder

_____

_____

I pledge to floss every night before brushing

Signed: Date:

Appendix 2 Vitamin C intervention

Everyday Activities Study

Please read this page carefully, and answer the questions at the bottom.

Taking vitamin C tablets

For the study we ask that you try to take a vitamin C tablet daily. You will be provided with vitamin C tablets for the duration of the study. This page will give you some information about the function of vitamin C, and the benefits of taking vitamin C supplements.

If you have any questions about this, please ask the researcher.

Please note that while we ask you to try to take a vitamin C tablet every day for the study, it is still your choice whether or not to do so, and you will not be penalised if you do not take the tablets.

Benefits of taking vitamin C tablets

PLEASE READ THE FOLLOWING CAREFULLY.

General benefits of vitamin C:

- Vitamin C is important for your immune system, skin, bones, and connective tissue.
- It promotes healing and helps your body absorb iron.
- The RDA (Recomended Daily Allowance) of vitamin C of 75-90mg a day is purely enough for avoiding deficiency, but higher levels (e.g. from supplements) are needed to get additional health benefits.
- Many foods contain vitamin C, but the cooking process removes much of the vitamin content.

Specific benefits of taking vitamin C tablets:

- It is always useful (and never harmful) to take vitamin C tablets to top up your vitamin C levels, even if you regularly get vitamin C from other sources. This is true up to a level of 2000mg per day.
- Taking vitamin C tablets can reduce the length and severity of colds.
- Vitamin C supplements can reduce the effects of ageing, as it is an antioxidant, and so protects against free radicals, which can damage the skin.
- For the same reason, higher intake levels of vitamin C may protect against cancer and cardiovascular disease. *(Note - vitamin C supplementation should not be taken by people undergoing cancer treatments as it can affect the treatment.)*
- Taking vitamin C supplements may help to protect against damage caused by exercise.
- Vitamin C supplementation may be useful for busy modern lifestyles, as it can be beneficial if your immune system is weakened due to stress.
- Taking vitamin C tablets may be advised for city dwellers -- as carbon monoxide (e.g. from pollution and cigarette smoke) destroys vitamin C.

LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE

Remembering to take your vitamin C tablet

You are more likely to take a vitamin C tablet every day if you make a decision about where and when you will do so. We ask for the purposes of the study that you keep the vitamins in the bathroom, so it would be best if you take them there. **If you don't already, it would be helpful for you to put a glass in the bathroom, so that this is easily available to help you take the vitamin C tablet.** Vitamin C tablets are most effective if you take them near meal times, so if possible, please try to take them in the morning, around breakfast time.

Decide now precisely when you will take the vitamin C tablets. You may want to think about your existing routines (e.g. what you do in the morning after you get up) and try to take vitamin C as part of this routine. For example, you may find it useful to take a tablet just after something else that you do regularly, such as having a shower, washing your face, or going to the toilet in the morning. Please type in below when you will try to take a vitamin C tablet every day.

32. When in your routine do you plan to take your vitamin C tablet (i.e. after which other activity and at what point in the day)? E.g. "I will take my vitamin C tablet in the morning after having a shower." *Please note this is only an example, not a recommended time, which should be specific to your own case.*

Continue >

Appendix 3 Prospective and Retrospective Memory Questionnaire

This measure was taken from (G. Smith et al., 2000). Prospective memory items (as opposed to retrospective memory items) are marked with a star. The items are coded 1=never, 5=very often, so a high score denotes more memory failures.

Here is a list of statements which you may or may not experience. Please indicate how often each situation happens to you by marking the appropriate box in each row.

Never	Rarely	Sometimes	Quite often	Very often

1. Do you decide to do something in a few minutes time and then forget to do it? *
2. Do you fail to recognise a place you have visited before?
3. Do you fail to do something you were supposed to do a few minutes later, even though it's there in front of you, like take a pill or turn off the kettle? *
4. Do you forget something that you were told a few minutes before?
5. Do you forget appointments if you are not prompted by someone else or a reminder such as a calendar or diary? *
6. Do you fail to recognise a character in a radio or television show from scene to scene?
7. Do you forget to buy something you planned to buy, like a birthday card, even when you see the shop? *
8. Do you fail to recall things that have happened to you in the last few days?
9. Do you repeat the same story to the same person on different occasions?
10. Do you intend to take something with you, before leaving a room or going out, but minutes later leave in behind, even though it is there in front of you? *
11. Do you mislay something you have just put down, like a magazine or glasses?
12. Do you fail to mention or give something to a visitor that you were asked to pass on? *
13. Do you look at something without realising you have seen it moments before?
14. If you tried to contact a friend or relative who was out, would you forget to try again later? *
15. Do you forget what you watched on television the previous day?
16. Do you forget to tell someone something you had meant to mention a few minutes ago? *

Appendix 4 Personal Need for Structure

This measure is from (Neuberg & Newsom, 1993).

Strongly disagree	**Disagree**	**Slightly disagree**	**Neither agree nor disagree**	**Slightly agree**	**Agree**	**Strongly agree**
1	2	3	4	5	6	7

Read each of the following statements and decide how much you agree with each according to your attitudes, beliefs and experiences. Please choose one of the following options for each question.

1. It upsets me to go into a situation without knowing what I can expect from it
2. I'm not bothered by things that interrupt my daily routine
3. I enjoy having a clear and structured mode of life
4. I like to have a place for everything and everything in its place
5. I enjoy being spontaneous
6. I find that a well-ordered life with regular hours makes my life tedious
7. I don't like situations that are uncertain
8. I hate to change my plans at the last minute
9. I hate to be with people who are unpredictable
10. I find that a consistent routine enables me to enjoy life more
11. I enjoy the exhilaration of being in unpredictable situations
12. I become uncomfortable when the rules in a situation are not clear

Appendix 5 Rational and Experiential Inventory

Items from (Pacini & Epstein, 1999). Respondents rated the items, on a 5-point scale that ranged from 1 (definitely not true of myself) to 5 (definitely true of myself).

The name of the subscale to which each item belongs appears in parentheses, ee = Experiential Engagement; ea = Experiential Ability; re = Rational Engagement; ra = Rational Ability. A minus sign (—) with a scale name denotes reverse scoring.

Definitely not true of myself	Slightly not true of myself	Neither true nor not true of myself	Slightly true of myself	Definitely not true of myself

Rationality scale

- I try to avoid situations that require thinking in depth about something, (re—)
- I'm not that good at figuring out complicated problems, (ra—)
- I enjoy intellectual challenges, (re)
- I am not very good at solving problems that require careful logical analysis, (ra—)
- I don't like to have to do a lot of thinking, (re—)
- I enjoy solving problems that require hard thinking, (re)
- Thinking is not my idea of an enjoyable activity, (re—)
- I am not a very analytical thinker, (ra—)
- Reasoning things out carefully is not one of my strong points, (ra—)
- I prefer complex problems to simple problems, (re)
- Thinking hard and for a long time about something gives me little satisfaction. (re—)
- I don't reason well under pressure, (ra—)
- I am much better at figuring things out logically than most people, (ra)
- I have a logical mind, (ra)
- I enjoy thinking in abstract terms, (re)
- I have no problem thinking things through carefully, (ra)
- Using logic usually works well for me in figuring out problems in my life, (ra)
- Knowing the answer without having to understand the reasoning behind it is good enough for me. (re—)
- I usually have clear, explainable reasons for my decisions, (ra)
- Learning new ways to think would be very appealing to me. (re)

Experientiality scale

- I like to rely on my intuitive impressions, (ee)
- I don't have a very good sense of intuition, (ea—)
- Using my gut feelings usually works well for me in figuring out problems in my life, (ea)
- I believe in trusting my hunches, (ea)
- Intuition can be a very useful way to solve problems, (ee)
- I often go by my instincts when deciding on a course of action, (ee)
- I trust my initial feelings about people, (ea)
- When it comes to trusting people, I can usually rely on my gut feelings, (ea)
- If I were to rely on my gut feelings, I would often make mistakes, (ea—)
- I don't like situations in which I have to rely on intuition, (ee—)
- I think there are times when one should rely on one's intuition, (ee)
- I think it is foolish to make important decisions based on feelings, (ee—)
- I don't think it is a good idea to rely on one's intuition for important decisions. (ee—)
- I generally don't depend on my feelings to help me make decisions, (ee—)
- I hardly ever go wrong when I listen to my deepest gut feelings to find an answer. (ea)
- I would not want to depend on anyone who described himself or herself as intuitive. (ee—)
- My snap judgments are probably not as good as most people's, (ea—)
- I tend to use my heart as a guide for my actions, (ee)
- I can usually feel when a person is right or wrong, even if I can't explain how I know, (ea)
- I suspect my hunches are inaccurate as often as they are accurate, (ea—)

Appendix 6 Big 5

Thie is a brief Big 5 personality measure (Gosling et al., 2003).

Here are a number of personality traits that may or may not apply to you. Please indicate how much you agree with the statements by selecting the appropriate response in each row. You should rate the extent to which the pair of traits applies to you, even if one characteristic applies more strongly than the other.

Strongly disagree	**Disagree**	**Slightly disagree**	**Neither agree nor disagree**	**Slightly agree**	**Agree**	**Strongly agree**
1	2	3	4	5	6	7

I see myself as:

a. Extraverted, enthusiastic.

b. Critical, quarrelsome.

c. Dependable, self-disciplined.

d. Anxious, easily upset.

e. Open to new experiences, complex.

f. Reserved, quiet.

g. Sympathetic, warm.

h. Disorganized, careless.

i. Calm, emotionally stable.

j. Conventional, uncreative.

Appendix 7 Information sheet and consent form

Information Sheet and Consent Form for Participants

Everyday Activities Study - Investigation of an activity monitoring system

Background

We are investigating a new electronic system to measure everyday activity within the home. The system is currently used in hospitals to track the movement of staff and equipment. If this system works in the home, it could be used to monitor whether elderly people are still capable of taking care of themselves, assisting in helping them to remain independent for longer, and raising the alarm if there are problems.

The study procedure:

The study lasts 4 months, but only around 2 hours of your time is required over that period. There will be sensors installed in your bathroom (see section below), and you will need to wear a sensor on your wrist for the duration of the study. There will be 3 visits to your home by the researcher, each including some questionnaires and interviews.

- **Session 1:**
  - Equipment is set up in your home.
  - It takes about 4 hours to set up the equipment, but less than 30 minutes of your time is needed.
- **Session 2 (after 4 weeks):**
  - Lasting 45 minutes with each participant separately.
  - You will be asked to try to make some small changes to your daily routine.
- **Online questionnaires (after 8 weeks and 12 weeks):**
  - You will be emailed with a link to a brief (10 minute) questionnaire which should be completed as soon as possible after it is received.
- **Session 3 (after 16 weeks):**
  - Equipment removed, and brief questionnaire and interview.
- Eight weeks after the equipment is removed there will be a brief emailed questionnaire, and a phone interview.

If you complete the study (to the third session), each person taking part in the household will be reimbursed £100 for their time.

The monitoring system and your home

The sensor system will be set up in your home for four months. This includes “object sensors” placed on: toothpaste, toothbrush cup, floss box, soap, taps, vitamin C bottle, toilet flush, toilet roll holder and shower/shower door. You will be given dental floss and vitamin C tablets for the duration of the study. There will also be two “location sensors” near the bathroom sink and the toilet, which are wired to a nearby plug socket, using thin, unobtrusive wires. Installing and removing the sensors will not leave any damage or visible sign in your home. Two plug sockets will be required to power the equipment (these are not expected to be in the bathroom). There will be a small use of your wireless internet capacity, of less than 1GB per month.

The monitoring system and you

During the four months of the study, you will be required to permanently wear a sensor on your wrist (similar in size and shape to a watch). This sensor is impact- and water-proof, so there is no need to ever take it off. The object sensors, and the sensor you wear, only record whether they are moving or not, whether they are in the household, and whether they are in range of the location sensors. There is no camera, microphone, or GPS ability in any of the sensors. You should just do what you normally do for the duration of the study. People who have taken part in earlier rounds of this study report that they stopped noticing the sensors after a short time, and that they were not bothered by the presence of the sensors. (The attached picture shows a person in the bathroom wearing the wrist sensor, the location sensor on the toilet, and object sensors on the toothpaste, toothbrush cup, floss and tap.)

If any of the sensors are unplugged, or if you remove the wrist sensor, we will be notified by the monitoring equipment.

Only adults aged 18 or over are eligible to take part. All data will be held in strictest confidence in accordance with the Data Protection Act 1998. If there is someone else in your household who is not taking part in the study, or if you have visitors during the study period, you can inform them that there is no possibility of their activities being recorded as they are not wearing a tag. If you have any questions, please do not hesitate to ask the researcher.

Investigator's contact details:
Gaby Judah
London School of Hygiene and Tropical Medicine, Keppel Street, London, WC1E 7HT
Gaby.Judah@lshtm.ac.uk

Consent Form

Title: Everyday Activities Study

This project has been approved by the Ethics Committee of the London School of Hygiene and Tropical Medicine.

Participant's Statement

I ……..agree that I have

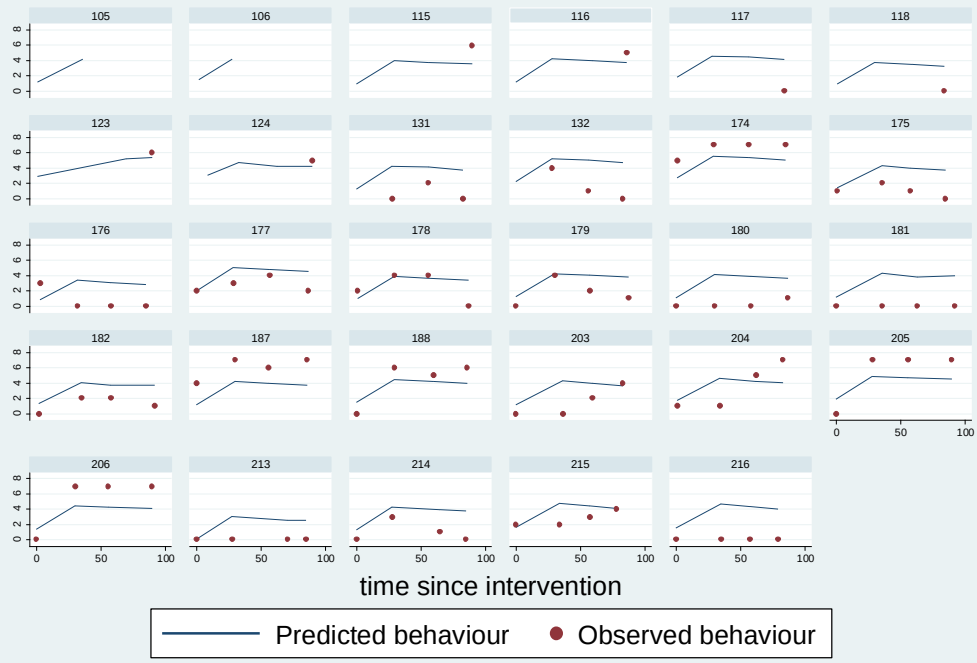
- read the information sheet and/or the project has been explained to me orally;
- had the opportunity to ask questions and discuss the study;
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research.
- understood that if I wish to take part in the study, I must wear the wrist sensor at all times.
- understood that there are procedures in place to ensure the safety of the researchers while they are working at my property.
- understood that if my home is unsuitable for the monitoring equipment, the researcher will inform me as early as possible during the first session and I will not be able to participate in the rest of the study.
- understood that taking part in the study is purely optional and I may withdraw from the study at any time.
- understood that all data will be kept strictly confidential.

Signed:

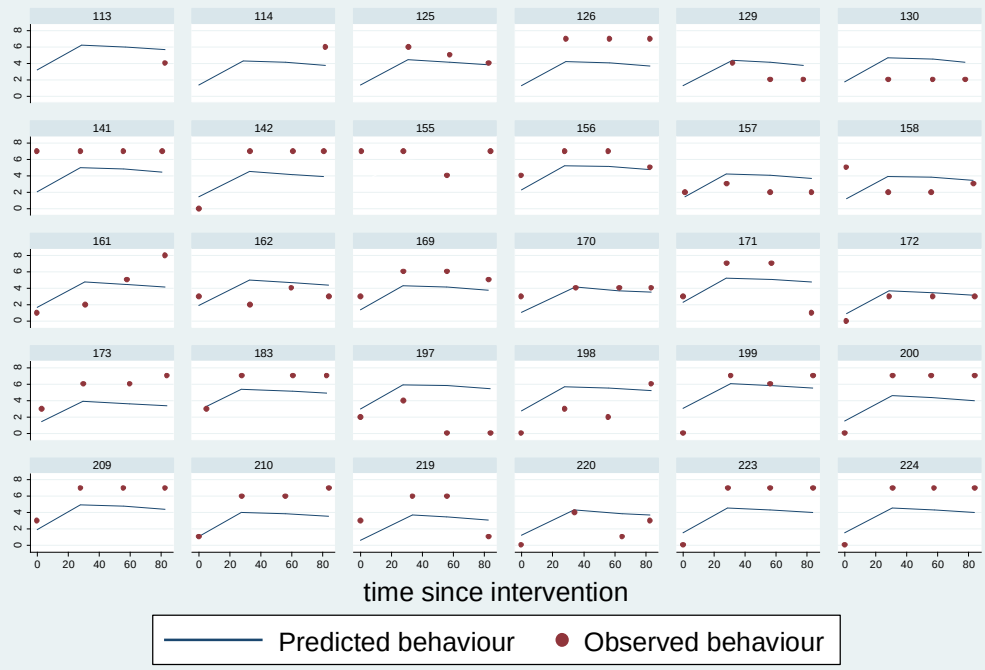
Date:

Appendix 8 Comparing fitted and observed results for flossing behaviour and automaticity

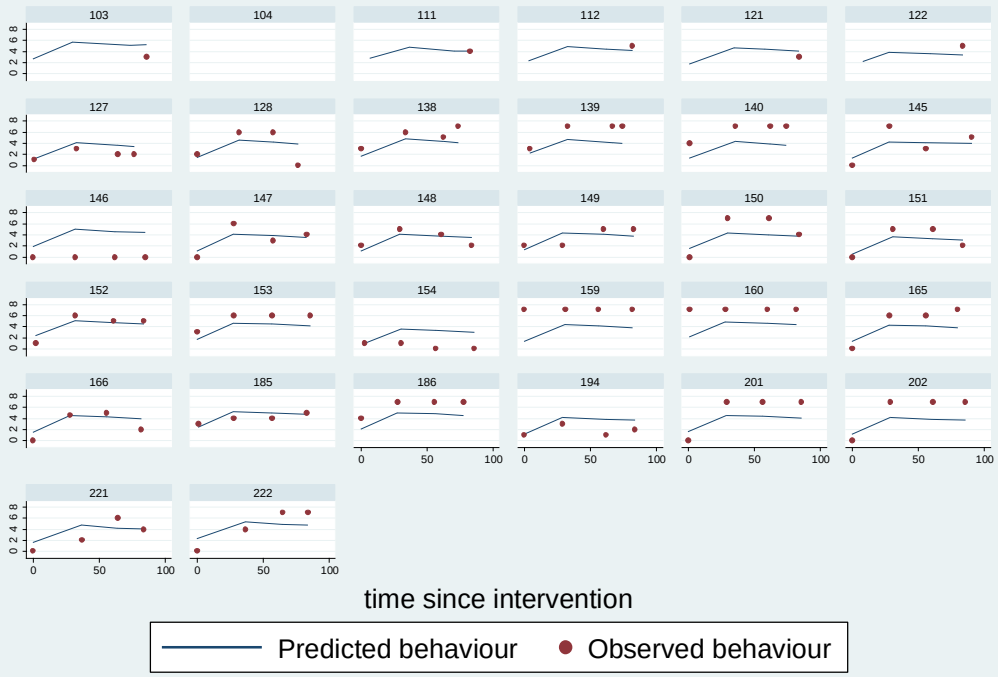
Self-reported flossing behaviour



After Attract group - graphs by participant



After Health group - graphs by participant



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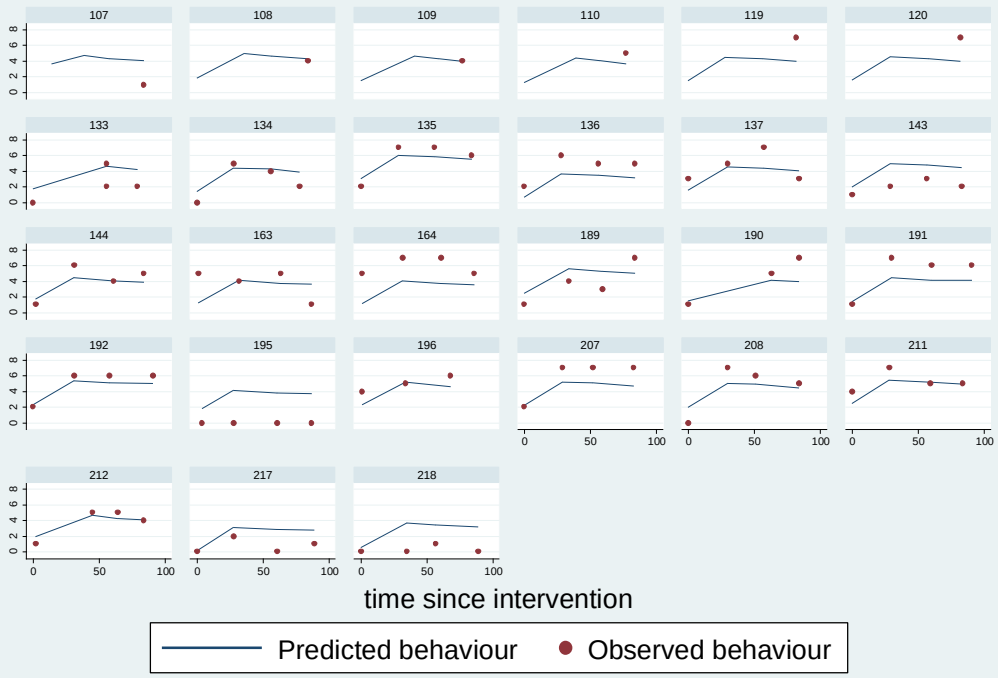
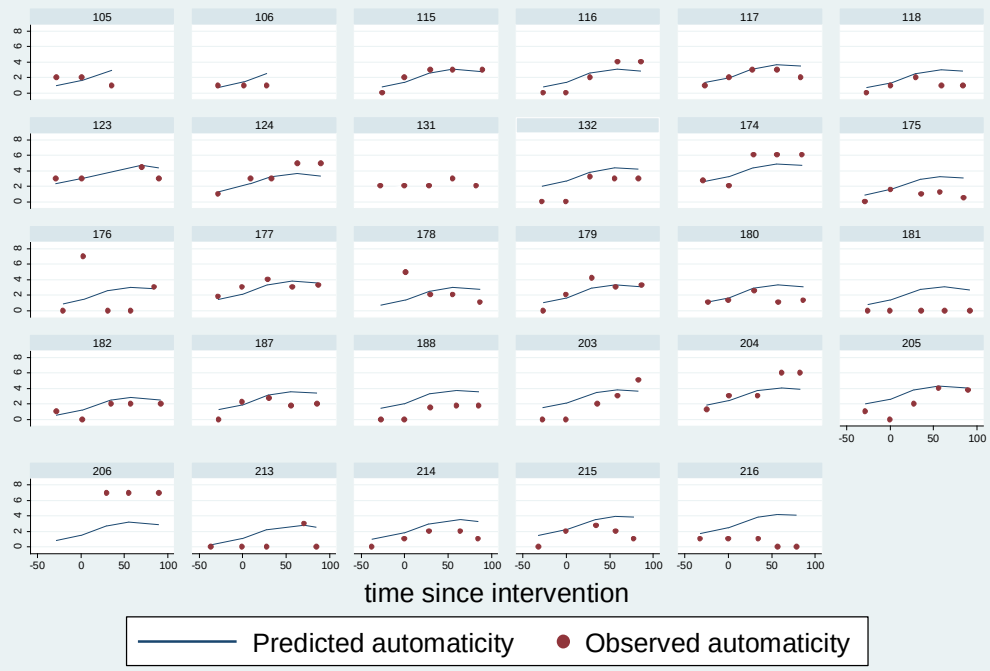
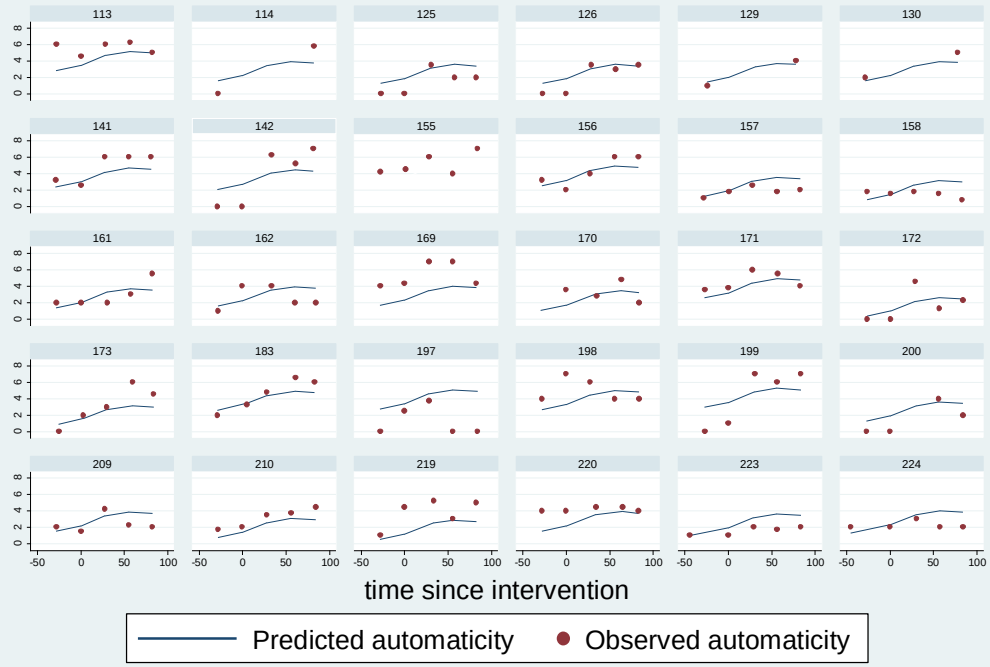


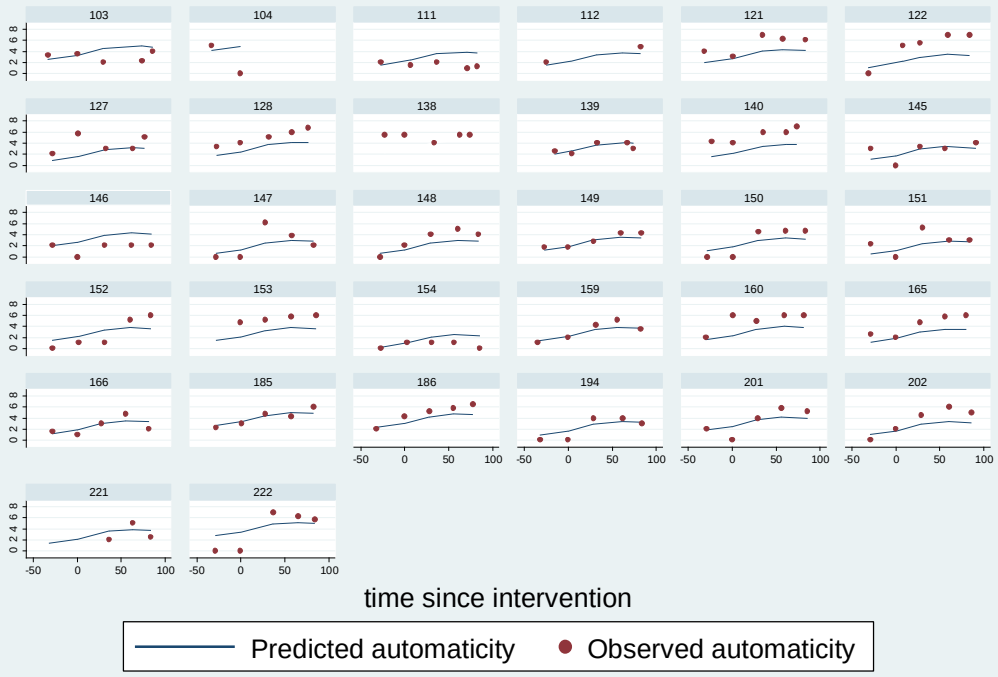
Before Health group - graphs by participant



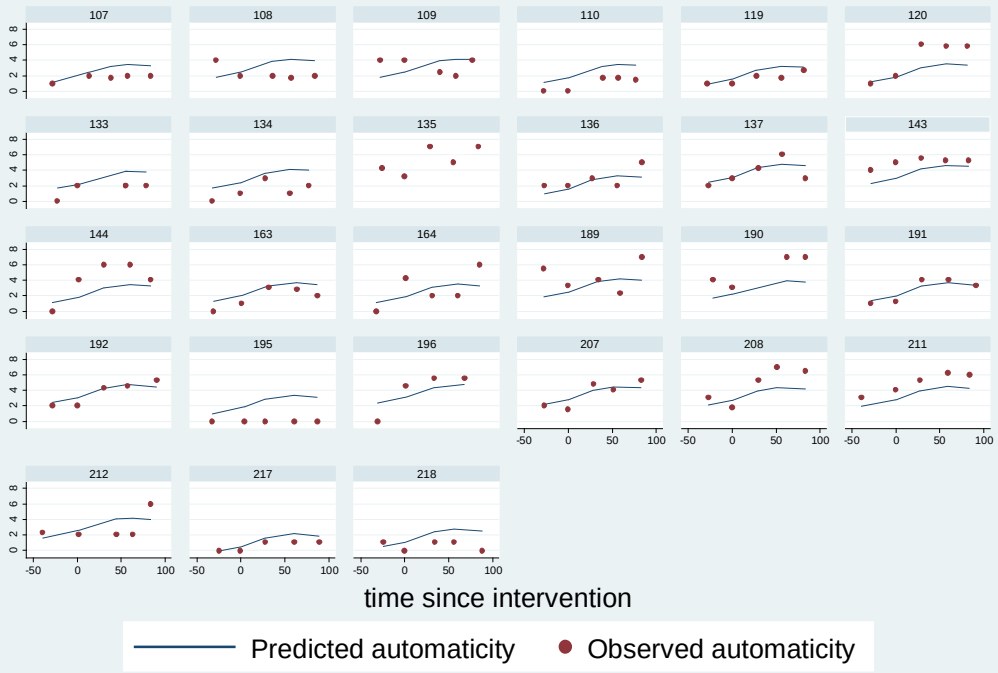
After Attract group - graphs by participant



After Health group - graphs by participant



Before Attract group - Graphs by participant



Before Health group - graphs by participant

Appendix 9 Results of screening SEM models for flossing

Predicting Automaticity at time 2	**Direct effect**		**Interaction**		**Effect on behaviour**	
	Coef	**p**	**Coef**	**p**	**Coef**	**p**
Attractiveness	*0.528*	*0.086*	-0.0435	0.455	-0.0131	0.952
Experiential attitude	**0.431**	**0.041**	-0.0345	0.411	**0.379**	**0.037**
Descriptive norm	0.217	0.351	0.00359	0.933	0.133	0.415
Reward	**0.627**	**0.003**	-0.0309	0.444	**0.533**	**0.003**
Health outcome evaluation	-0.0897	0.856	0.00911	0.924	0.209	0.567
Attractiveness outcome evaluation	0.06	0.858	0.013	0.885	0.29	0.31
Intention	0.284	0.126	-0.0156	0.742	**0.351**	**0.003**
Context stability	*0.247*	*0.058*	-0.0462	0.274	**0.56**	**<.001**

Predicting Automaticity at time 3	**Direct effect**		**Interaction**		**Effect on behaviour**	
	Coef	**p**	**Coef**	**p**	**Coef**	**p**
Attractiveness	0.228	0.326	-0.0256	0.591	0.0826	0.495
Experiential attitude	0.00991	0.962	0.0378	0.38	*0.235*	*0.064*
Descriptive norm	0.111	0.562	0.0112	0.751	**0.225**	**0.018**
Reward	0.0991	0.574	0.0298	0.392	**0.207**	**0.044**
Health outcome evaluation	Model didn't converge after 131 iterations					
Attractiveness outcome evaluation	0.0269	0.887	-0.059	0.413	0.0175	0.91
Intention	0.124	0.435	-0.0731	0.101	0.157	0.2
Context stability	0.0612	0.56	*-0.0736*	*0.077*	**0.217**	**0.026**

Predicting Automaticity at time 4	**Direct effect**		**Interaction**		**Effect on behaviour**	
	Coef	**p**	**Coef**	**p**	**Coef**	**p**
Attractiveness	0.196	0.251	0.0323	0.358	-0.0187	0.894
Experiential attitude	0.2248	0.203	0.0166	0.615	**0.289**	**0.024**
Descriptive norm	0.0559	0.724	0.028	0.366	-0.0527	0.624
Reward	**0.371**	**0.026**	-0.00833	0.791	0.193	0.137
Health outcome evaluation	0.556	0.119	-0.0183	0.845	0.0301	0.919
Attractiveness outcome evaluation	**0.624**	**0.022**	-0.1049	0.141	-0.107	0.599
Intention	-0.0489	0.747	0.0532	0.128	0.171	0.267
Context stability	0.137	0.19	-0.0404	0.231	0.161	0.149
Flossing better than brushing?	-0.254	0.905	0.0632	0.157	0.12	0.465

Variables marked in bold were retained to the second level of screening, as they had at least one significant pathway. These results were from the SEM version A, with the covariates measured four weeks prior to the outcomes of behaviour and automaticity. When the screening was repeated with contemporaneous time (Version B, as discussed in the results section of Chapter 3), the same variables were seen to be significant and to be accepted for the second level of screening.

Predicting Automaticity at T2	Direct effect		Interaction		Effect on behaviour	
	Coef	p	Coef	p	Coef	p
Rewarding experience	**0.785**	**0.002**	-0.066	0.177	**0.504**	**0.034**
Descriptive norm	-0.073	0.685	0.046	0.149	-0.105	0.459
Intention	0.239	0.274	-0.038	0.581	0.279	0.26
Context stability	**0.233**	**0.006**	**-0.036**	**0.018**	**0.382**	**0.004**
Attractiveness outcome evaluation	0.027	0.867	0.043	0.162	-0.074	0.73

(Ran attractiveness outcome evaluation model with no interaction term as did not converge)

Predicting Automaticity at T3	Direct effect		Interaction		Effect on behaviour	
	Coef	p	Coef	p	Coef	p
Rewarding experience	0.228	0.298	0.023	0.594	0.2	0.2
Descriptive norm	-0.114	0.516	0.02	0.536	-0.001	0.994
Intention	0.164	0.31	**-0.104**	**0.019**	-0.015	0.923
Context stability	**-0.021**	**0.813**	**-0.021**	**0.365**	**0.131**	**0.153**
Attractiveness outcome evaluation	**-0.208**	**0.05**	0.044	0.203	0.038	0.819

Predicting Automaticity at T4	Direct effect		Interaction		Effect on behaviour	
	Coef	p	Coef	p	Coef	p
Rewarding experience	**0.474**	**0.029**	-0.004	0.905	0.276	0.15
Descriptive norm	-0.004	0.986	0.013	0.734	-0.094	0.503
Intention	-0.022	0.886	0.009	0.812	0.156	0.373
Context stability	0.103	0.291	-0.027	0.398	0.14	0.204
Attractiveness outcome evaluation	0.219	0.427	-0.068	0.27	-0.154	0.485

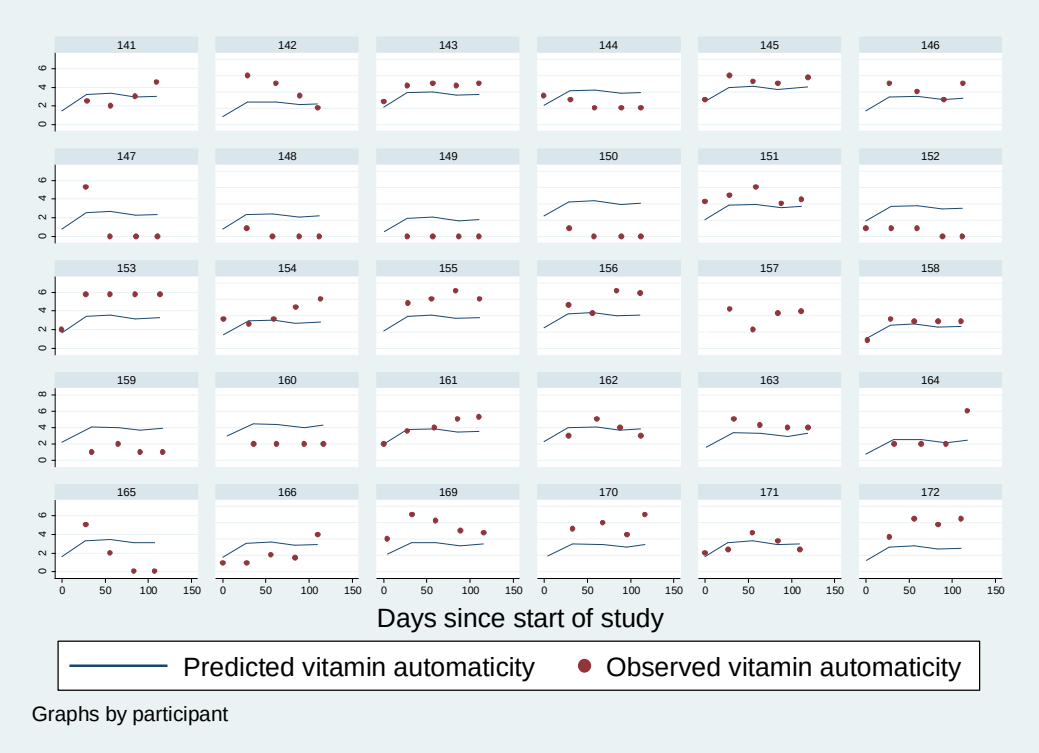
Screening level 2 - stability and intention now have paths to automaticity as covariates (norm and attract outcome evaluation have paths to behaviour only)

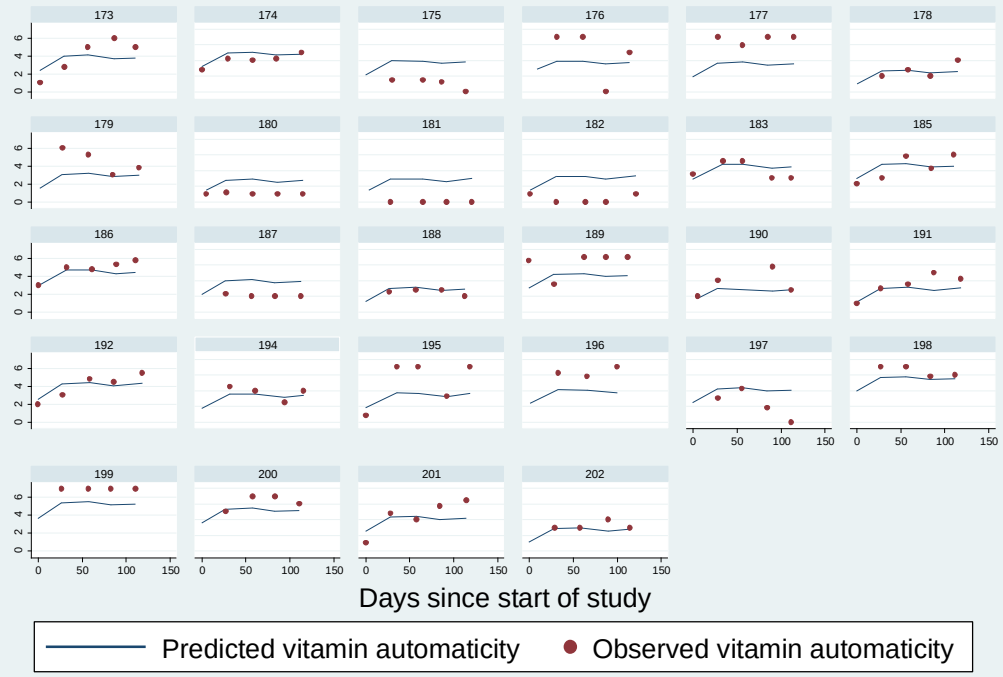
Variables marked in bold were retained to the final model, as they had at least one significant pathway.

Appendix 10 Comparing fitted and observed values for taking vitamin C tablets

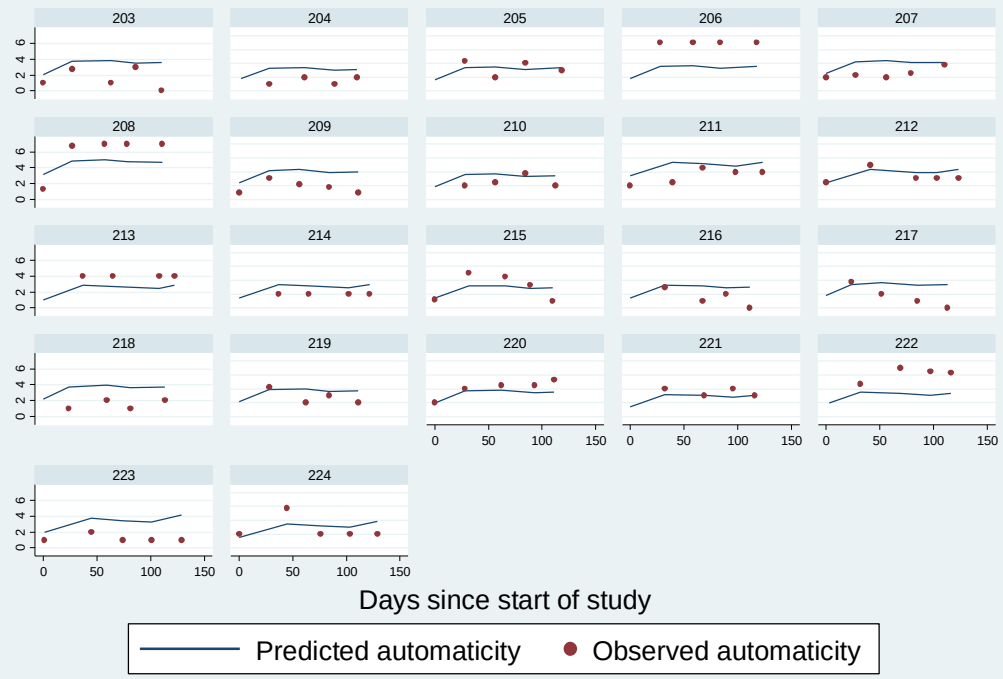
Automaticity

(Predicted behaviour scores are not shown, as the final model only contained an effect of linear time.)





Graphs by participant



Graphs by participant

Appendix 11 Vitamin C SEM results including attitude variables

The table below shows the vitamin C SEM results using global attitude as the potentially rewarding variable.

Past behaviour and past automaticity refers to behaviour and automaticity measured at the previous timepoint.
The model fit was assessed using the Comparative Fit Index (CFI), where values approaching 1 indicate better fit. Significant variables are marked with a *

	T1, N=84		**T2, N=79**		**T3, N=79**		**T4, N=79**	
	Coeff	p	Coeff	p	Coeff	p	Coeff	p
Hypothesised predictors of automaticity								
Past automaticity	0.167	.388	0.615*	<.001	0.534*	<.001	0.549*	<.001
Behaviour	0.203*	.009	0.168*	.004	0.269*	<.001	0.086	.217
Intention	0.704*	.021	0.011	.948	0.251	.148	0.021	.921
Intention * Behaviour Interaction	-0.099	.056	0.001	.980	-0.077	.054	0.002	.964
Global attitude	-0.370	.409	.336	.223	-0.162	.432	0.349	.224
Global attitude * Behaviour Interaction	0.087	.291	0.033	.547	0.059	.164	0.004	.941
Stability	.008	.967	0.132	.276	-0.075	.449	0.233*	.021
Stability * Behaviour Interaction	0.108*	.020	0.013	.678	0.062*	.039	0.016	.608
Hypothesised predictors of behaviour								
Past behaviour	0.065	.428	0.663*	<.001	0.493*	<.001	0.544*	<.001
Past automaticity	-0.063	.812	-0.245	.063	0.038	.778	0.218	.098
Intention	0.102	.546	0.467*	.006	0.332	.090	.035	.803
Global attitude	0.323	.298	-0.177	.454	0.074	.742	-0.147	.462
Stability	0.908*	<.001	0.275*	.045	0.247	.100	0.207	.053
Hypothesised predictor of past automaticity								
Past behaviour	0.040	.386	0.432*	<.001	0.428*	<.001	0.525*	<.001
Hypothesised predictor of intention								
Global attitude	0.471*	.009	0.833*	<.001	0.638*	<.001	0.882	<.001
CFI	0.337		.681		0.616		0.652	

The table below shows the vitamin C SEM results using vitamin belief as the potentially rewarding variable. (This variable was only measured at T0, T1 and T4, which is why only models for two timepoints were constructed.)

	T1, N=84		**T2, N=79**	
	Coeff	p	Coeff	p
Hypothesised predictors of automaticity				
Past automaticity	0.185	.332	0.548*	<.001
Behaviour	-0.194	.571	-0.045	.859
Intention	0.604*	.017	0.143	.468
Intention * Behaviour Interaction	-0.087	.051	-0.019	.621
Vitamin belief	-0.299	.522	0.145	.468
Vitamin belief * Behaviour Interaction	0.104	.223	0.037	.578
Stability	0.038	.829	0.206*	.042
Stability * Behaviour Interaction	0.108*	.017	0.025	.427
Hypothesised predictors of behaviour				
Past behaviour	0.111	.083	0.537*	<.001
Past automaticity	-0.057	.834	0.217	.098
Intention	0.205	.218	0.052	.714
Vitamin belief	-0.410	.190	-0.234	.356
Stability	0.862*	<.001	0.207	.052
Hypothesised predictor of past automaticity				
Past behaviour	0.037	.416	0.525*	<.001
Hypothesised predictor of intention				
Vitamin belief	0.359	.118	1.124*	<.001
CFI	0.184		0.477	