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Practice makes perfect: Repeatedly dealing with response conflict facilitates its identification and speed of resolution

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ABSTRACT

People repeatedly encounter response conflicts (i.e., self-control dilemmas between long-term and short-term goals). A longitudinal study was conducted to investigate how resolution of response conflict develops over time. Participants pursued a long-term goal. The design entailed pre- and post-measurements, as well as daily/weekly measures using a mobile application over a range of 10–110 days. Of the 180 people participating in the pre-measurement, 90 also completed the post-measurement. Over time, people became faster at successfully resolving response conflicts. The same response conflicts became bigger over time. Repeatedly being confronted with response conflicts facilitates resolution of these conflicts, by improving the identification of these conflicts, resulting in faster resolution.

1. Introduction

Many everyday situations are characterized by the presence of *competing tendencies*, or self-control dilemmas in which we have to decide between an option that serves our short-term goals and is immediately satisfying (e.g., sweets with our coffee, staying in on a rainy night) and an option that serves our long-term goal, but lacks the immediate satisfaction (e.g., some raw veggies as a snack, going to the gym despite the rain). People with higher levels of trait self-control are known to be better at resolving response conflicts (Friese, Hofmann, & Wiers, 2011; Gillebaart, Schneider, & De Ridder, 2016; Stillman, Medvedev, & Ferguson, 2017). Consistently overcoming these so-called *response conflicts* by choosing the long-term option leads to positive outcomes, as is illustrated abundantly by self-control research: People who are better at overcoming response conflict are happier, healthier, do better at work and school, and have more satisfying interpersonal relationships (Cheung, Gillebaart, Kroese, & De Ridder, 2014; De Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012; Moffitt et al., 2011; Tangney, Baumeister, & Boone, 2004). Although self-control related response conflicts have been extensively studied, this is done almost exclusively for isolated instances, entailing single conflicts occurring once, often in artificial settings. As this diverges from real-life circumstances in which response conflicts are often recurring (e.g., the same triple chocolate cookie at the work cafeteria every day), this paper will focus on how repeatedly being confronted with response conflicts affects how they are identified and resolved. Specifically, the size and speed of resolution of conflicts over time was investigated in a longitudinal study on goal pursuit.

Evidently, the size of a self-control conflict impacts how hard it is to identify and resolve this conflict (Bargh, Chaiken, Govender, & Pratto, 1992; MacLeod, 1991). One may intuitively assume that with a bigger conflict, more self-control resources are needed to make the decision that is congruent with long-term goals, making a bigger conflict harder to resolve. Interestingly, this would imply that smaller conflicts should not pose a problem, since they are easily overcome or resolved, requiring only few self-control resources. Indeed, previous research has followed this line of reasoning for some time (e.g., Hofmann, Baumeister, Förster, & Vohs, 2012; Trope & Fishbach, 2000). More recently however, research has demonstrated that the association between the magnitude of a conflict and how easily it is identified and subsequently handled may be more complex, and may in fact be reversed.

In some situations, the dilemma between a short-term and long-term goal may be evident, and therefore quickly identified. Someone who is on a diet to lose a few pounds will have no trouble identifying a conflict when he or she is confronted with a delicious chocolate cake at a friend's birthday. Likewise, someone who has a work deadline the next day, but is invited to a night with friends watching the newest episode of their favorite series will know that, although immediately satisfying, there is an inherent conflict in

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this situation between a short-term goal of enjoying oneself in a social situation on the one hand, and being successful and appreciated at work on the other hand (or, a third option, losing sleep and having both, which is also not a promising long-term strategy). In these situations, response conflict may be relatively obvious, allowing for appropriate action (e.g., allocating resources such as attention towards the conflict). However, in many situations, a self-control response conflict may not be this obvious. Having that one plain biscuit with your tea instead of refraining, over-eating at a lunch buffet at a conference, having one too many drinks on a Thursday night, having dessert in a restaurant following big portions of appetizers and entrees, or opting to stay home instead of going for a run after a busy day at work; all are common situations that may not invoke big feelings of dilemma or conflict, but can be detrimental to one's long-term goals when occurring regularly (e.g., consumption of unhealthy snacks has been identified as a factor in overweight whereas people do not regard snacking as such: Forslund, Torgerson, Sjostrom, & Lindroos, 2005; Howarth, Huang, Roberts, Lin, & McCrory, 2007). These smaller conflicts can thus form a significant threat to long-term goal pursuit, but tend to fly under the radar of conflict identification. Paradoxically, this may mean that a bigger conflict is 'better', in terms of conflict identification.

Supporting this view on the underlying processes of self-control dilemmas, a model on response conflict resolution by Myrseth and Fishbach (2009) has divided the process of response conflict resolution into two stages: identification and resolution. In this model, being able to identify an ongoing conflict is important, and in fact imperative, if one is to resolve the conflict. When a response conflict goes unnoticed (i.e., is not identified as such), chances are that no self-regulatory resources will be allocated for inhibiting an impulse, suppressing a habit, or deliberating the consequences of a decision, increasing the probability that one is guided by impulse, hedonistic motives, and cues from the environment. This would then result in indulging in the short-term gratification. Indeed, the model by Myrseth and Fishbach shows that when a conflict is *not* identified, there is indulgence, whereas when conflict is identified, a temptation is more likely to be resisted. This supports the notion of the adaptive nature of bigger conflicts over smaller ones.

Research based on Counteractive Control Theory has also supported these suggestions. Phrased in terms of temptations, this theory posits that being confronted with a temptation (i.e., a gratifying short-term option that is in conflict with a long-term goal, forming a response conflict) in fact may activate long-term goal pursuit (Kroese, Evers, & De Ridder, 2011; Myrseth, Fishbach, & Trope, 2009; Trope & Fishbach, 2000). The threat that comes with a temptation may facilitate conflict identification, allowing for resolution. Interestingly, this adaptive goal activation effect only holds for *strong* temptations – causing bigger response conflicts (e.g., a home-made birthday cake, a big bag of fatty crisps), whereas *weak* temptations – causing smaller response conflicts (e.g., a frozen factory apple pie, a small portion bag of the same crisps) lack this inherent capacity for being identified as a threat. As a result, weaker temptations can have the paradoxical effect of being indulged in more. Thus, whereas stronger temptations have the potential to elicit long-term goal-directed behavior, weaker temptations may not trigger such self-regulatory processes, making them harder to resist (Kroese et al., 2011). These lines of theory and research converge on the idea that although counterintuitive, we may benefit from bigger response conflict because we are able to identify them quicker, allowing for more adequate resolution of conflict. Therefore, if one were to become better at resolving the same response conflicts over time, this conflict may actually have to appear or become bigger, and not smaller.

Although there have been a number of studies into if and how self-control capacity itself can be improved (for a meta-analysis see Friese, Frankenbach, Job, & Loschelder, 2017), no research has been done into how being repeatedly confronted with response conflict affects its identification and resolution. This is remarkable, since people often encounter the same or similar environments repeatedly in their daily routines (e.g., home-work routes, grocery shopping). From theories and models on self-control and response conflict, it is unclear how self-control and conflict resolution develop over time. Therefore, we have conducted a longitudinal study in which participants were confronted repeatedly with response conflicts that were relevant to a long-term goal they indicated at the start of the study to be of importance to them. This can provide more insight into how response conflicts are handled in real-life situations and environments.

The identification and resolution of conflict was measured using a mouse tracking paradigm (Freeman & Ambady, 2010). This implicit measure allows for assessing the response conflict process unobtrusively, without relying on people's self-reports as those tend to focus on outcomes only (Gillebaart et al., 2016). In this paradigm, participants are provided with a computerized task. They are confronted with a decision (e.g., between a picture of a tasty yet unhealthy food item and a healthy yet less tasty food item), and are instructed to move their computer mouse, or in the case of a mobile application, swipe their finger, towards one of the two choice items at the upper corners of the screen. In the current study, participants were instructed to move towards the option that represented their desired behavior, or long-term goal. Unbeknownst to the participant, the computer mouse or finger trajectory from start to response is recorded. By analyzing these trajectories, several aspects of response conflict can be assessed (Wojnowicz, Ferguson, Dale, & Spivey, 2009). When participants start a trial, response conflict will show up as a 'pull' from the non-selected option, causing a curvature in the trajectory from start to end of trial. A complete lack of conflict should be accompanied by a straight line from start to response, whereas any curvature deviating from the straight line, towards the unselected response indicates how much the participant is 'pulled' by the other, conflicting choice option. This paradigm allows for analysis of the magnitude of 'pull', which can be considered a proxy for conflict size, as well as response time and other response conflict dynamics.

Based on studies that show improvements in self-control behaviors (Friese et al., 2017), it was firstly hypothesized that over time, participants would become better at resolving response conflicts. As in previous research this was reflected by a faster resolution of the response conflict in a mouse tracking paradigm (Gillebaart et al., 2016), it was predicted that participants would become faster in resolving the response conflict over time. Secondly, it was hypothesized that the size of response conflicts would *increase* with repeated exposure over time, facilitating conflict identification. *Maximum deviation from the straight line* (and the corresponding *area under the curve)* are thought to be a mouse tracking proxy for the size of the response conflict. As such, we predicted an increase in maximum deviation over time. A bigger conflict may be easier to solve because it is identified easier (Myrseth & Fishbach, 2009), and a maximum deviation earlier in time is related to faster resolution of the conflict (Gillebaart et al., 2016). Therefore, thirdly, we hypothesized that a quicker identification of conflict would occur over time, signified by an earlier point of maximum deviation.

During the study, trait self-control was assessed repeatedly as well. Trait self-control at the pre-measurement was treated as an exploratory factor to examine whether self-control level was associated with trends in response conflict development.

2. Methods[1]

2.1. Participants and design

The population register of Utrecht (the Netherlands) was used to recruit a community sample, in combination with a social media campaign and the university's alumni register. All individuals between the age of 18 and 65 were eligible. Although possession of a smartphone was desired due to the nature of the study, we were able to provide participants with a smartphone for the duration of the study if they did not possess one (*N* = 5). Participants were invited to join the study if they would be interested in forming a good habit, in order to reach a long-term goal. No incentive was awarded for participation. During the study, the research team organized activities to sustain commitment and engagement, such as a lecture, newsletter, lotteries, and personal notes and Christmas cards.

All participants indicated they wanted to change a habit in the health, sustainability, interpersonal, or financial domain. The data was collected over 110 days (approximately three months). The design entailed pre- and post-measurements administered at a university location, as well as daily/weekly measures using a mobile application over a range of 10–110 days (*M* = 75.8, *SD* = 27.7), with 10 days being the minimum including at least one of the measures after the pre-measurement. In total 180 people participated in the pre-measurement, of which 90 participated in the post-measurement. The mouse tracking task that was performed on a mobile device every other day by 156 participants. The number of occasions participants performed the task ranged from 2 to 53 (*M* = 24.8, *SD* = 13.8).

2.2. Procedure

This study was part of a larger longitudinal prospective study on habit formation, and as such multiple measures were included that were not relevant to the current research.[2] A community sample was recruited. At the start of the study, participants indicated what type of behavior they wanted to improve and practice over the course of the study. Participants could choose between behaviors related to health, interpersonal, financial, or environmental issues, and could choose from a set of 60 combinations of behaviors and contexts. It was emphasized that the selected behavior needed to be personally relevant to them, and that they had trouble regularly performing the behavior, so that there was both motivation and room for improvement for the behavior. Depending on the context participants chose, they could opt for a specific behavior linked to that context. For example, in the health context, participants could opt for eating more fruit during breakfast or to exercise when arriving home from work. In the interpersonal context, people could for example choose to increase contact with their neighbors or be more patient with their partner. Stimulus materials were adapted to selected behavioral goals.

Participants started with a pre-measurement at the university's lab and were instructed to use the study mobile app daily for measurements and questionnaires. Participants received a reminder every morning via the mobile app. By the end of the study, participants returned to the lab for the post-measurement. The study was approved by the faculty ethical review board.

2.3. Materials

Mouse tracking task. Resolution of response conflicts was measured by means of a mouse tracking paradigm (Freeman & Ambady, 2010) that included a categorization task. This task was administered via computer (in the pre- and post-measurement) and via mobile phone (for the intermediate data collection).

Task instructions were to focus first on the manikin (representing the participant) that would appear at the bottom of the screen, and to place either their computer mouse or finger on the manikin, depending on the apparatus they were operating at that moment. Instructions further specified that two pictures would appear in the left and right upper corners of the screen, and that one of these pictures would fit their behavioral goal, including an example, while the other would not fit that behavioral goal. Participants were instructed to move their manikin to the picture that fit their behavioral goal as soon as possible after starting the trial.

At the start of each trial, a fixation icon (a manikin representing the participant) appeared at the center bottom of the screen after a 1000 ms blank screen (in the mobile application) or after clicking a start button (in the pre- and post-measurement). Once the fixation icon was clicked or touched, stimuli appeared at the right and left upper corners of the screen. Stimuli consisted of goal-congruent and goal-incongruent pictures, tailored to the participant's selected long-term goal. Participants were instructed to move their computer mouse (in the pre- and post-measurement) or their finger (in the mobile application) towards the goal-congruent stimulus (see Fig. 1).

Following an overview of the goal-congruent and goal-incongruent stimuli, participants were presented with 20 trials including goal-congruent and goal-incongruent stimuli. Location of the goal-congruent stimuli was counterbalanced over trials. After having reached one of the stimuli at the top of the screen, participants received response time feedback. If participants did not respond within 750 ms of the stimuli appearing, a message appeared saying 'Please start moving faster' (mobile application only). If there was a > 10 s non-response, a message appeared saying 'Please move your mouse/finger to the object that fits your goals as fast as possible'.

Streaming x and y coordinates of the mouse/finger were recorded with a sampling rate of 60 Hz (on computer screens during pre- and post-measurement). Sampling rate on mobile phones was not registered due to a variety of smartphones being used. However, a common sampling rate on smartphones is 60 Hz. Several measures were extracted to assess response conflict aspects. *Response time* was operationalized as the time it took from the stimuli appearing to reaching one of two stimuli. *Maximum deviation* and *area under the curve* were used to assess the size of the conflict. Area under the curve refers to the geometric area between the straight line between fixation and stimulus (the 'conflict free' trajectory) and the actual trajectory followed in the trial. Maximum deviation indicates the largest deviation between these two trajectories. On mobile phones, maximum deviation and area under curve were both measured on a scale ranging from -1 (maximum possible deviation away from the desirable alternative) through 0 (no deviation) to +1 (maximum possible deviation towards the desirable alternative), in which the deviation was corrected for the size of the screen. On computer screens, trials were always presented in a 600*800 pixel frame, and maximum devia-

[1] This study was not pre-registered. Materials, code, and data are available on the Open Science Framework [https://osf.io/73tys/].

[2] At the pre- and post-measurement, the Self-Report Habit Index (Verplanken & Orbell, 2003), Brief Self-Control Scale (Tangney et al., 2004), questions about goal importance and motivation, and a lexical decision task were administered in addition to the measures relevant to the current study. During pre-measurement, a measure of general attributional style (Peterson et al., 1982) was also administered, and ad the post-measurement, an ego depletion task was performed. During the study, several measures were administered via the participants' mobile phone. On a daily basis, participants were asked about their behavioral performance, contextual encounters of temptations, and attributions of failure. On a (bi-)weekly basis, the Self-Report Habit Index, Brief Self-Control Scale, Willpower Beliefs (Job, Dweck, & Walton, 2010), and General Self-Efficacy Scale (Jerusalem & Schwarzer, 1979) were administered, in addition to questions about goal importance and motivation. Moreover, the mouse tracker task was alternated with a lexical decision task every other day.

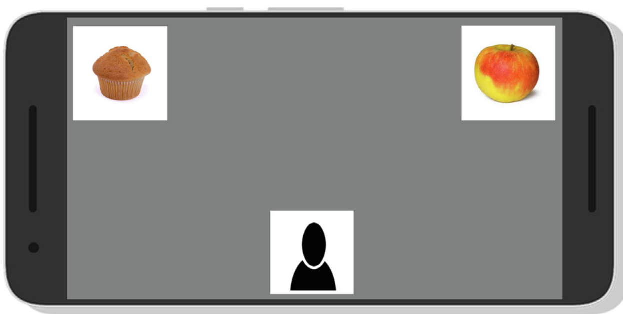

Fig. 1. Schematic presentation of a mouse tracking trial on a mobile phone.

tion and area under the curve were measured in pixels. Area under the curve and maximum deviation illustrate the spatial attraction of the alternative response, making it a proxy for strength of the conflict. The time it takes to reach this point of maximum deviation was also recorded.

Trait self-control. Trait self-control was assessed with the Brief Self-Control Scale (Tangney et al., 2004). This scale consists of 13 statements (e.g., 'People would say I have iron self-discipline'). For each statement, participants indicated to what extent they felt the statement was applicable to them on a scale from 1 (not at all) to 5 (very much). The scale proved reliable with a Cronbach's alpha of 0.79.

2.4. Data analysis

Data from the pre- and post-measurement were analyzed separately from the timeseries data because of the different apparatus used (computer vs. mobile phone). For the pre- and post-measurements, mouse tracker variables at time of pre-measurement as well as post-measurement were compared using nonparametric Wilcoxon signed rank tests. In these analyses, the mouse tracker variables at pre- and post-measurement were the averaged variables over the valid (maximum 20) trials, deleting trials in which goal-incongruent choices were made and trials that were too slow (i.e., more than 2.5 standard deviations slower than the participant's mean response time; Brewer, 2011; Ratcliff, 1993). In addition, multilevel analysis of the mouse tracker variables for all (maximum 40) trials of a participant at the pre-measurement and the post-measurement were carried out to examine whether trait self-control at pre-measurement was related to the change in these mouse tracker variables, using a similar procedure as described below for the timeseries data.

Timeseries data were analyzed using multilevel analysis in R, with the generalized linear mixed-effects model (GLMER), using Maximum Likelihood estimation. For the response time and the time for reaching maximum deviation a lognormal distribution was used, whereas for maximum deviation and area under curve a normal distribution seemed more adequate. First, growth curve modeling was used to examine linear and quadratic trends over time in response time, maximum deviation and area under curve. Next, the influence of self-control was examined, using trait self-control as measured on the pre-measurement. The linear trend was measured in days but standardized in the analyses, and the quadratic trend was the square of this standardized linear trend. Moreover, in the analyses, some of the dependent variables were rescaled (i.e., maximum deviation and area under curve were multiplied by 100, adding 1 for time until reaching maximum deviation) in order to improve the estimation of the (normal or lognormal) model. These transformations did not change the results, and untransformed variables are presented in the Figures to facilitate interpretation of the findings.

3. Results

3.1. Drop-out analyses

In this study, 180 individuals participated in the pre-measurement. Of these participants, 154 were included in the main analysis of the timeseries, and 90 also participated in the post-measurement. In the timeseries there were two additional individuals included, who did not participate in the pre-measurement. For these individuals, in the timeseries analyses, the first app-measurement of self-control was used to replace the missing self-control measure at the pre-measurement.

To examine whether there was evidence for selective attrition from the study, the 154 participants who were included in the timeseries analyses were compared to the 26 individuals who only filled out the pre-measurement and did not participate any further. Moreover, the 90 individuals who filled out the post-measurement were compared to the 90 participants who dropped out of the study before the post-measurement. The two additional participants in the timeseries were not included in these drop-out analyses.

With regard to the background variables, it was found that there was no selective attrition with regard to gender, $\chi^2(1) < 1.0$, $p > 0.6$. However, individuals who were included in the timeseries (M = 31.74, SD = 12.66) and in the post-measurement (M = 29.15, SD = 12.86) on average were younger than those who dropped out early (respectively M = 39.42, SD = 13.92, and M = 36.49, SD = 11.79), $t(147) = 2.00$, $p < 0.05$ and $t(147) = 3.58$, $p < 0.001$, respectively. There were missing data for age for 31 participants at the pre-measurement. Participants in the timeseries and in the post-measurement did not differ in the chosen behavior from those who dropped out, $\chi^2(10) < 13.42$, $p > 0.20$.

Table 1 shows the mouse tracking variables at the pre-measurement for individuals who were retained or dropped out of the study, separately for the timeseries and for the post-measurement.

Nonparametric Wilcoxon signed rank tests showed that those who dropped out before the timeseries and those who dropped out before the post-measurement, had slower response time than those who were retained in these analyses, standardized test statistics respectively $z = -3.10$, $p < 0.01$, and $z = -4.33$, $p < 0.001$. For maximum deviation, area under curve, and time until reaching maximum deviation at the pre-measurement, there were no differences between those who did or did not complete the post-measurement, $-1 < z < 1$, $p > 0.50$. However, those who were retained in the timeseries analyses had a smaller maximum deviation, $z = -2.43$, $p < 0.05$, and smaller area under curve, $z = -2.37$, $p < 0.05$, than those who dropped out early, whereas time until maximum deviation was reached did not differ, $z = 1.02$, $p = 0.31$.

We conclude that those who were retained in our study were younger, and probably as a result, on average responded faster and more adequately, i.e., following a straighter line, in the mouse tracking at the pre-measurement than those who dropped out early from the study.

3.2. Pre- and post-measurement

There were 90 complete pre- and post-measurement datasets. Trials in which the goal-incongruent option was chosen or trials that were too slow were removed from the dataset before testing the hypotheses. Mean age of participants (73 females, 17 males) was 29.73 (SD = 12.86).

To test the hypothesis on changes in response conflict resolution over time, we conducted a set of nonparametric Wilcoxon

Table 1
Selective attrition with regard to mouse tracking variables at pre-measurement.

	Participation in timeseries				Participation in post-measurement			
	No (N = 26)		Yes (N = 154)		No (N = 90)		Yes (N = 90)	
	M	SD	M	SD	M	SD	M	SD
Response time	1,348.37	400.73	1,148.30	599.30	1,309.03	710.99	1,045.37	363.17
Maximum deviation	79.14	59.41	49.83	43.34	56.63	49.14	51.50	44.81
Area under curve	33.75	23.99	21.97	17.97	24.73	20.00	22.62	18.69
Time until maximum deviation	171.25	69.82	184.05	74.97	178.62	76.93	185.77	71.61

signed rank tests between response time, time of maximum deviation, maximum deviation, and area under the curve at pre- and post-measurement. In line with our hypothesis, the overall mouse tracker response time decreased over time, indicating that with repetition, participants became faster in resolving the response conflict trials (M_{pre} = 1045.37 ms, SD = 363.17 ms; M_{post} = 862.56 ms, SD = 315.70 ms, Wilcoxon standardized test statistic $z = -5.11$, $p < 0.001$). Interestingly, maximum deviation (the maximum deviation from a straight 'conflict free' line between start and response) increased with time, in line with our hypothesis that faster resolution would be accompanied by changes in maximum deviation. Between pre- and post-measurement, maximum deviation increased significantly (M_{pre} = 51.50, SD = 44.81; M_{post} = 68.10, SD = 48.42, z = 3.74, $p < 0.001$), indicating that with repetition, the response conflict became larger. Similar to maximum deviation, area under the curve increased over time, indicated by a significant difference between pre- and post-measurement (M_{pre} = 22.62, SD = 18.69; M_{post} = 29.56, SD = 22.35, z = 3.46, $p < 0.01$). The point in time at which the maximum deviation took place did not significantly differ between pre- and post-measurement (M_{pre} = 185.77, SD = 71.61; M_{post} = 199.82, SD = 64.95, z = 1.81, p = 0.07).

To explore whether trait self-control measured at the pre-measurement stage was related to changes between pre- and post-measurement of the mouse tracker variables, multilevel analyses were performed for each of the mouse tracker variables (response time, maximum deviation, area under curve, and time until reaching maximum deviation), entering both a dummy variable for time (pre- or post-measurement) and trait self-control at pre-measurement, and in a second step the interaction between time and trait self-control. In none of the multilevel analyses, trait self-control contributed significantly to the regression (p > 0.20), nor were any of the regression coefficients of the interaction terms significant (p > 0.14). This suggest that the changes in response conflict resolution over time were similar for all baseline levels of trait self-control.

3.3. Timeseries data

In total, there were 77,299 trials of 156 participants on 3864 participant days. Of these trials, 2707 (3.5%) were errors, in that the wrong (goal-incongruent) option was chosen. These trials were removed from analysis. Moreover, as advised (Brewer, 2011; Ratcliff, 1993), response times faster or slower than 2.5 standard deviations of each participant's mean response time, were replaced by missing values. No fast responses were found, but 1296 (1.7%) responses were discarded as too slow. The remaining 73,296 trials were analyzed. Moreover, it was checked whether there were participants with a mean response time faster or slower than 2.5 standard deviations than the general mean response time. There were 10 participants with a slow mean response time. Discarding these participants and all their trials did not change the results substantially, and therefore these relatively slow participants and their trials remained in the analyses.

The response time of valid trials ranged from 320 to 32205 ms (M = 1,291 ms, SD = 760 ms), and was heavily positively skewed with a high kurtosis. Maximum deviation of the 73,281 valid trials (occasional missing data for maximum deviation on 15 trials) ranged from −0.78 to 0.90 (M = 0.060, SD = 0.108), and area under curve ranged from −0.29 to 0.39 (M = 0.006, SD = 0.020). Both variables were also positively skewed, with high kurtosis, mostly due to a substantial number of positive and negative outliers. When transforming these outliers to less extreme values, similar results were found as with the original variables, therefore the results with original variables are presented here. Finally, the time for reaching maximum deviation ranged from 0 to 10558 ms (M = 353 ms, SD = 258 ms). As the time for reaching maximum deviation was strongly dependent on the total response time, the latter variable was statistically controlled in analyses of the time for reaching maximum deviation.

Trends over time. Response time was analyzed using multilevel modeling using a lognormal distribution. Both the linear trend and the quadratic trend were significant ($p < 0.001$), as can

Table 2
Multilevel regression of response time (ms, lognormal distribution).

Predictor	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Intercept	7.189***	7.071***	7.070***	7.071***
Linear trend		−0.142***	−0.1***42	−0.141***
Quadratic trend		0.07***3	0.073***	0.071***
Trait self-control (SC)			−0.034	−0.002
Linear trend × SC				0.038***
Quadratic trend × SC				−0.013
Fit (−2 log L)	1160931***	1155666***	1155665***	1,155,515
Δ fit		5266***	1	150***
df		2	1	2
Variance				
Random intercept	34894***	29543***	29386***	29187***
Residual	425508***	396086***	396086***	395281***
ICC	0.08			
R^2 level 1 (trial)		8%	8%	8%
R^2 level 2 (person)		15%	16%	16%

Note: Values denoted with *** reached significance with p < 0.001.

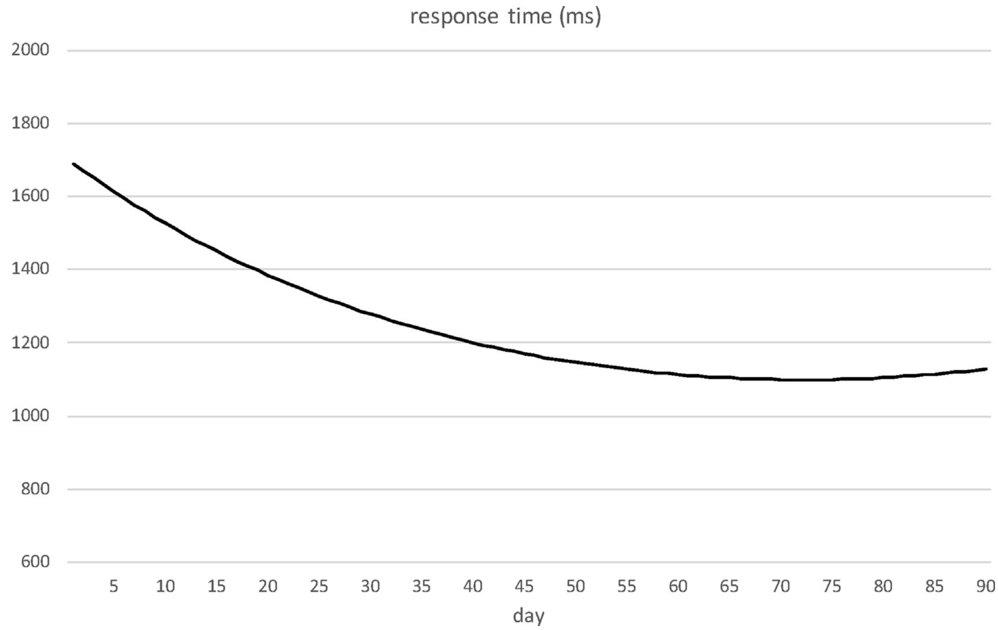

Fig. 2. Trend over time for response time.

be seen in Table 2, Model 2. The fitted regression line for the mean response time is shown in Fig. 2. The mean response time declined in the first 50 days of the training, and then stabilized at the level of approximately 1100 ms.

Maximum deviation was analyzed using a normal distribution as reference. As can be seen in Table 3, Model 2, for maximum deviation there was also a linear ($p < 0.01$) and a quadratic trend ($p < 0.001$) of time, which are presented in Fig. 3. In contrast to response time, we see that mean maximum deviation increased somewhat in the first 30 days and stabilized a little under the level of 0.06, showing that maximum deviation of the straight line on average was limited.

For area under curve, the results in Table 4, Model 2 showed that the linear trend was not significant, but the quadratic trend of time was significant ($p < 0.01$). As can be seen in Fig. 4, area under curve increased in the first few weeks and declined on later trials.

Time until maximum deviation was reached was first corrected for the (log-transformed) total response time, as shown in Model 2 of Table 5. In Model 3, the linear trend was just significant ($p < 0.05$), but the quadratic trend was not. As can be seen in Fig. 5, the time at which maximum deviation was reached increased slightly over time.

Self-control. For the association of time series patterns with trait self-control, the pre-measurement (grand mean centered) was examined. Self-control was examined in a multilevel regression of response time, while correcting for the linear and quadratic trend. This regression did not result in a significant association between self-control and response time. Similar analyses were done for maximum deviation of the straight line, area under curve, and time until maximum deviation. In none of these analyses, self-control contributed significantly to the regression (see Model 3 in Tables 2–4, and Model 4 in Table 5).

Finally, it was examined whether the linear and quadratic trends in response time and maximum deviation were associated with trait self-control. This was the case for both the linear and quadratic trend in the response time ($p < 0.001$), and for the linear trend in maximum deviation ($p < 0.001$) and area under curve ($p < 0.05$), as reported in Model 4 in Tables 2–4. As can be seen in Fig. 6, among individuals low in self-control the reduction in response time in the first few weeks was stronger than among those high in self-control. With regard to maximum deviation from

Table 3
Multilevel regression of maximum deviation.

Predictor	Model 1	Model 2	Model 3	Model 4
Intercept	5.756***	5.942***	5.919***	5.924***
Linear trend		0.140**	0.140**	0.136**
Quadratic trend		−0.155***	−0.155***	−0.168***
Trait self-control (SC)			0.711	−0.695
Linear trend × SC				0.277***
Quadratic trend × SC				0.058
Fit (−2 log L)	546359***	546341***	546339***	546321***
Δ fit		18.4***	1.6	18.4***
df		2	1	2
Variance				
Random intercept	16.47***	16.39***	16.22***	16.19***
Residual	100.38***	100.36***	100.36***	100.33***
ICC	0.14			
R^2 level 1 (trial)		0.1%	0.2%	0.3%
R^2 level 2 (person)		0.5%	1.5%	1.7%

Note: Values denoted with ** reach significance with $p < 0.01$, values denoted with *** reach significance with $p < 0.001$. Maximum deviation was multiplied by 100 in these analyses.

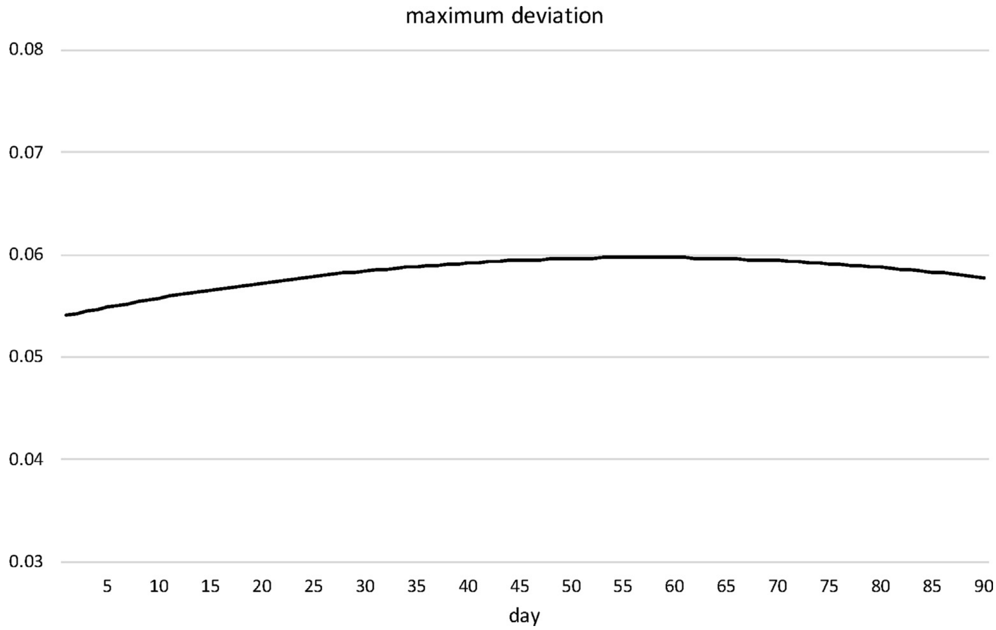

Fig. 3. Trend over time for maximum deviation.

Table 4
Multilevel regression of area under the curve.

Predictor	Model 1	Model 2	Model 3	Model 4
Intercept	0.605***	0.628***	0.625***	0.626***
Linear trend		0.004	0.004	0.004
Quadratic trend		−0.021**	−0.021**	−0.023**
Trait self-control (SC)			−0.073	−0.074
Linear trend × SC				0.030*
Quadratic trend × SC				0.009
Fit (−2 log L)	300449***	300441***	300440***	300434***
Δ fit		7.8*	0.9	6.7*
df		2	1	2
Variance				
Random intercept	0.303***	0.302***	0.301***	0.300***
Residual	3.507***	3.506***	3.506***	3.506***
ICC	0.08			
R^2 level 1 (trial)		0.0%	0.1%	0.1%
R^2 level 2 (person)		0.0%	0.6%	0.7%

Note: Values denoted with * reached significance with $p < 0.05$, values denoted with ** reached significance with $p < 0.01$, values denoted with *** reached significance with $p < 0.001$. Area under curve was multiplied by 100 in these analyses.

the straight line, Fig. 7 shows that the increase in the maximum deviation was found especially among individuals high in self-control, whereas an initial increase seemed to reverse to a decrease among individuals low in self-control in the second half of the examined period. Fig. 8 shows largely similar results for the area under the curve deviating from the straight line: among individuals high in self-control, the area under curve stabilized after an initial increase, whereas among individuals low in self-control a slight decrease was found in later trials. Interactions between trait self-control and trends over time were not significant for the response time until maximum deviation (controlling for total response time), as can be seen in Model 5 in Table 5.

4. Discussion

A longitudinal study was conducted to investigate how identification and resolution of response conflict develops over time in real-life settings. In line with our first hypothesis, results from the pre- and post-measurement as well as the timeseries data demonstrated that over time people became faster at resolving response conflicts in a way that was congruent with their long-term goals. Interestingly, this development co-occurred with the same response conflicts becoming bigger over time, as indicated by a larger deviation from a conflict-free movement pattern, in accordance with our second hypothesis. Our third hypothesis was not supported: after correction for the total response time, the time until maximum deviation was reached became slightly slower over time rather than faster.

Trait self-control was not associated with the changes in these mouse tracker variables between pre- and post-measurement. However, exploratory analyses of the timeseries data demonstrated interactions between trait self-control measured at the beginning of the study and the linear and/or quadratic trends in response time, maximum deviation, and area under the curve. In general, lower levels of self-control were associated with a steeper decline in response time in the first phase of the study. In terms of the size of the conflict, there was a larger increase for those with higher levels of self-control, while at the same time there seemed to be a slight decrease at the end of the study for those with lower

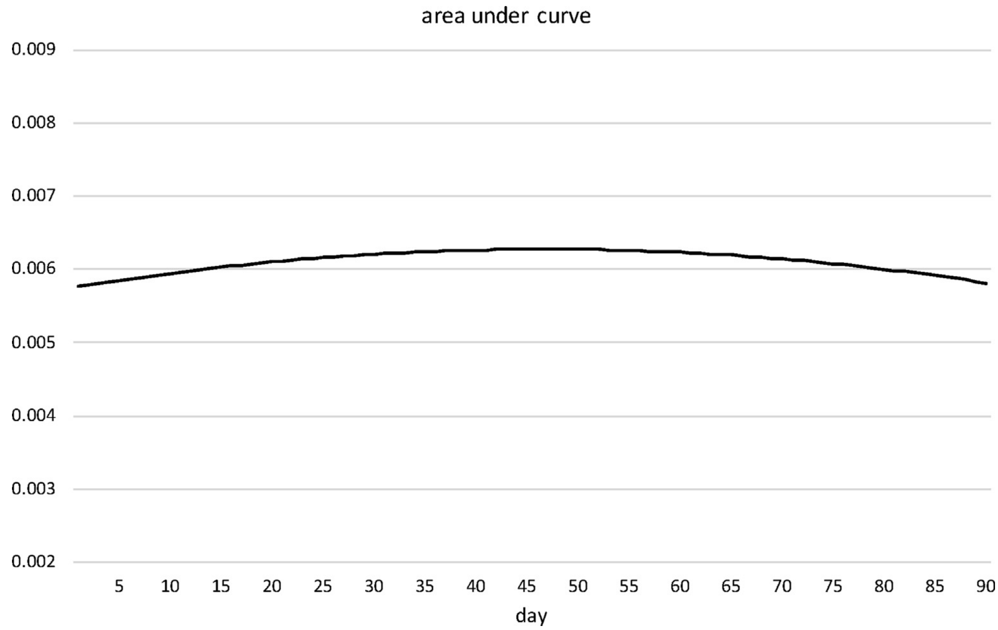

Fig. 4. Trend over time for area under the curve.

Table 5
Multilevel regression of time until maximum deviation (lognormally transformed).

Predictor	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	5.798***	5.351***	5.321***	5.322***	5.323***
Response time (log)		0.063***	0.067***	0.067***	0.067***
Linear trend			0.006	0.006	0.006*
Quadratic trend			−0.003	−0.003	−0.003
Trait self-control (SC)				0.019	0.021
Linear trend × SC					0.004
Quadratic trend × SC					−0.001
Fit (−2 log L)	1008637***	1008584***	1008579***	1008579***	1008578***
Δ fit		52.5***	5.2	0.1	0.7
df		1	2	1	2
Variance					
Random intercept	7102***	7076***	7072***	7066***	7069***
Residual	53537***	53499***	53495***	53495***	53495***
ICC	0.12				
R^2 level 1 (trial)		0.1%	0.1%	0.1%	0.1%
R^2 level 2 (person)		0.4%	0.4%	0.5%	0.5%

Note: Values denoted with * reached significance with $p < 0.05$, values denoted with ** reached significance with $p < 0.01$, values denoted with *** reached significance with $p < 0.001$. 1 ms was added to time until reaching maximum deviation in these analyses (to include trials with 0 ms; in a lognormal analysis, a value of 0 is not valid).

levels of self-control. Taken together, these results are in line with our hypotheses: people indeed became 'better' in resolving response conflict when they were repeatedly confronted with them, illustrated by the faster response times of successfully resolved conflicts. Maximum deviation and area under the curve both increased over time, indicating that while resolved faster, the conflicts themselves became bigger.

Previous research on response conflict has mostly neglected the observation that people do not experience single response conflicts in a vacuum, but rather are participants in a dynamic environment that is packed with stimuli that are either congruent or incongruent with one's long-term goals. As such, the current study adds to the existing body of knowledge on how people handle response conflicts by studying recurring response conflicts entailing stimuli that are relevant to people's individually relevant long-term goals. Results demonstrated that repeatedly being confronted with similar response conflicts is associated with a facilitation of its resolution: People became faster in selecting stimuli that were in line with their long-term goals over time. Interestingly, the current study at the same time also sheds light on why this might be the case. Whereas intuitively, one may think recurring response conflicts would become smaller and therefore easier to resolve, the opposite occurs: Over time, people experienced the same response conflicts as larger, while at the same time being able to resolve them faster. This is in line with research on response conflicts and counteractive control that posits that one needs to be able to identify a conflict before being able to allocate the appropriate control resources to resolve it (Myrseth & Fishbach, 2009), and that bigger conflicts are easier to identify (Kroese et al., 2011).

A higher level of trait self-control has been associated with better resolution of response conflict in previous research (Gillebaart et al., 2016). In general, people with higher levels of trait self-control resolve these types of conflict faster. In the current study, level of trait self-control interacted with the progress people made over time. People with a lower level of trait self-control started out slower in resolving response conflicts compared to people with a higher level of trait self-control, but also showed a bigger decrease in response time over time as compared to people with a higher

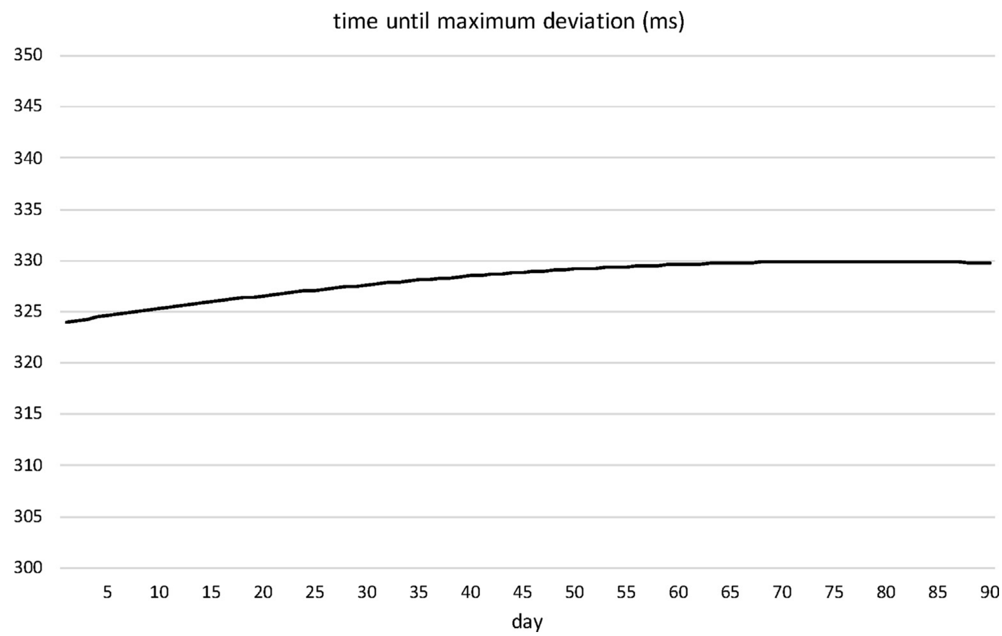

Fig. 5. Trend over time for time until maximum deviation.

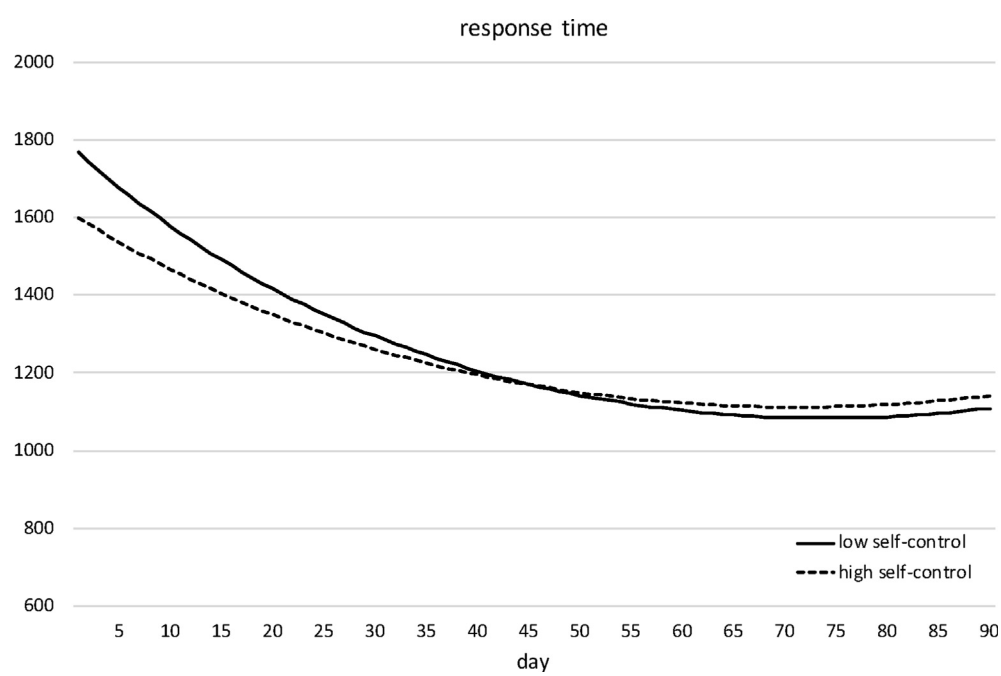

Fig. 6. Trend over time in response time for individuals high (+1 SD) and low (−1 SD) in self-control.

level of trait self-control. These are promising results, as they show that the people with the most 'room for improvement' in terms of response conflict resolution, namely those with lower levels of trait self-control, also show the steepest learning curve. Other research on self-control has demonstrated similar patterns, for example that attending to consumption leads to larger decreases in consumption enjoyment for people with low as compared to high levels of self-control (Redden & Haws, 2013). In terms of self-control training, this shows interesting avenues for training and intervention, adding to recent findings on the 'trainability' of self-control (De Ridder, Van der Weiden, Gillebaart, Benjamins, & Ybema, 2019; Friese et al., 2017). It must be noted however, that for the size of response conflicts, interactions with trait self-control are far less clear-cut and could be interpreted as people with lower level of self-control showing a quicker flattening of their learning curve compared to those with a higher level of self-control.

There are some limitations to the current study that urge caution when interpreting the results. One limitation is that participants were able to choose their own long-term goal at the beginning of the study. This ensured that the goals and temptations were important to people, and reflected real-life dilemmas that people come across in their daily lives, but it precluded having a similar, controlled set of response conflicts for all participants. No differences were found for the different areas of long-term goals (i.e., health, sustainability, interpersonal, and financial goals) in terms of the results, but in future research, one could opt for a

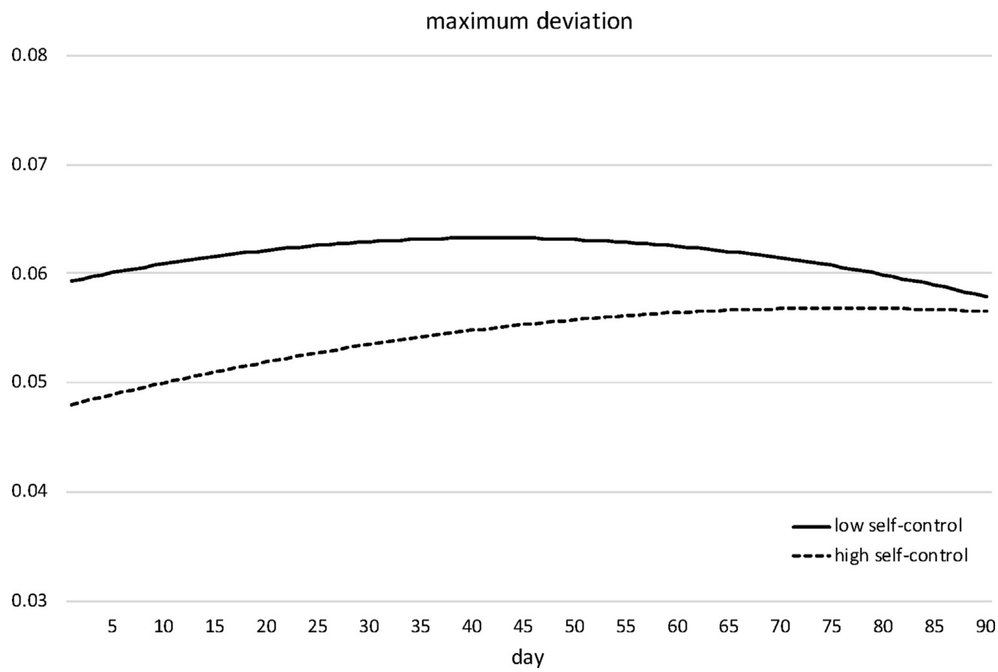

Fig. 7. Trend over time in maximum deviation for individuals high (+1 SD) and low (−1 SD) in self-control.

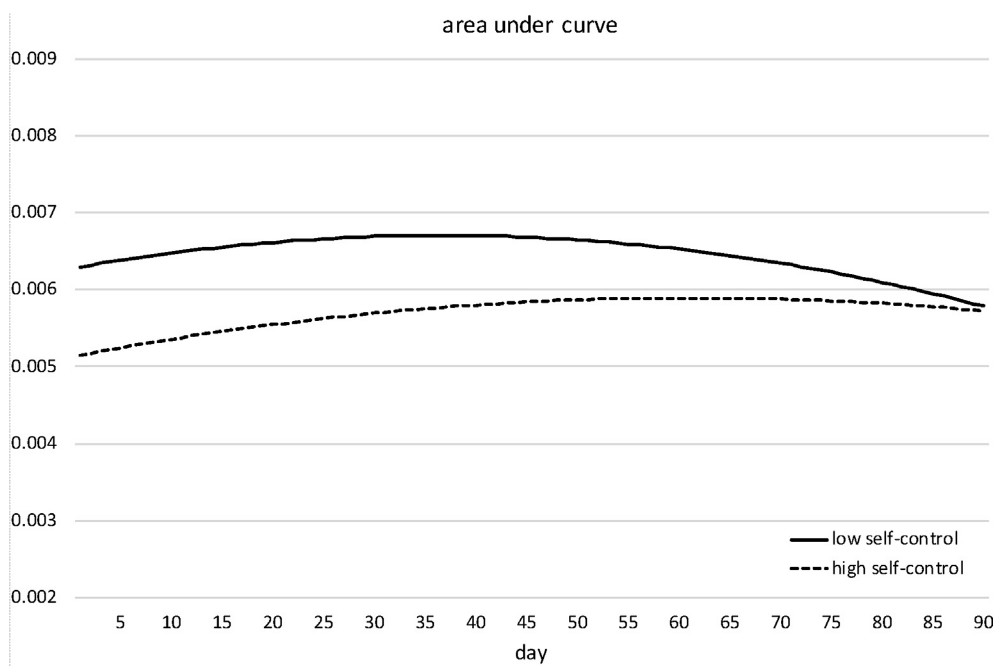

Fig. 8. Trend over time in area under curve for individuals high (+1 SD) and low (−1 SD) in self-control.

more controlled setting when building on these results. On the other hand, participants received information, instructions, and monitored for their progress. This allowed for a semi-controlled setting, but in terms of ecological validity, results may not generalize to spontaneous daily-life version of these processes taking place. Another limitation to keep in mind is related to drop-out. People who completed the study were on average younger, and tended to respond faster and with a better outcome (i.e., a more conflict-free trajectory) than people who dropped out at an earlier point in the study. These variables may be related (e.g., age correlates with increased reaction times; Thompson, Blair, & Henrey, 2014). One reason for drop-out of older participants may be that younger participants tended to commit to completing the study in order to get course credit, which was not available for non-students. Importantly, the type of goals that people set was no different for those who dropped out or finished the study.

Strengths of the study include the innovative design: it is the first in its kind to apply a longitudinal design to the implicit measures of response conflict resolution. Furthermore, although using mouse trajectories as an implicit measure of conflict has increased significantly over the past decade (e.g., Buttlar & Walther, 2018; Freeman, Dale, & Farmer, 2011; Schneider, Gillebaart, & Mattes, 2019; Schneider & Schwarz, 2017), using a mobile application to do so opens up possibilities for future use, and demonstrates that tracking 'swiping' movements produces similar results.

Future avenues for research based on these findings are abundant: More explicit measures of response conflict, self-control, and self-control dilemmas may be an interesting addition to the current results. As these explicit self-report measures do not always match the implicit measures (Gillebaart et al., 2016; Gillebaart, 2018), measuring both builds towards a more comprehensive framework. Moreover, a behavioral outcome measure would be a valuable addition to this line of research, to assess the impact of conflict resolution dynamics. Furthermore, recent research has shown that people with a high level of self-control use several strategies above and beyond impulse inhibition when dealing with response conflicts (Duckworth, Gendler, & Gross, 2016; Gillebaart & de Ridder, 2015), insight that should be combined with how people handle response conflict dilemmas on the more fundamental level that was employed in the current work. Finally, whether or not dealing with response conflict can become habitual (and thus effortless) is an interesting direction for research, especially considering recent studies on self-control and habits (Adriaanse, Kroese, Gillebaart, & De Ridder, 2014; Galla & Duckworth, 2015).

5. Concluding remarks

Everyone holds long-term goals having to do with health, wellbeing, and happiness. Everyone also encounters temptations that are not in line with these long-term goals on a regular basis. A pessimist would conclude that we are destined to fail: being bombarded with temptation would surely thwart our long-term goal pursuit. However, people do succeed, and those who are consistently able to deal with response conflict in their environment are happier and healthier for it (De Ridder et al., 2012; Moffitt et al., 2011; Tangney et al., 2004). The conclusions we can draw from the current study are therefore much more optimistic in nature: Repeatedly being confronted with response conflicts actually facilitates resolution of these conflicts, by improving the identification of these conflicts, resulting in faster resolution. Moreover, this facilitating effect may be largest for those who need it most.

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Author contributions

MG, AW, DR contributed to the design the study. AW contributed to data collection. MG, JB, and JY contributed to data analysis. MG, AW, DR, JB, and JY all contributed significantly to writing the manuscript.

Declaration of Competing Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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