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Are trait self-control and self-control resources mediators of relations between executive functions and health behaviors?

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The authors declare no conflict of interests.

Consent for publication

All the authors listed in the by-line have agreed to the by-line order and to the submission of the manuscript in this form.

Contributors

C.F., M.d.C and T.D. designed the study protocol. C.F. designed the analyses. M.D. C.F, M.d.C, R.B, and T.D. collected the data. C.F. analyzed the data. C.F., M.d.C and T.D. drafted the manuscript. A.C., R.B, M.B, and B.C. critically appraised the manuscript and significantly contributed to its content and structure. All authors approved the final version of the manuscript.

Data sharing

Data and code for the analysis are available on OSF at

https://osf.io/hpsjw/?view_only=6e28c8307294494e9eec45d2670efd8d

1

Abstract

2 This study investigated associations between executive functions (i.e., inhibition, working
3 memory, cognitive flexibility) and individual differences in self-control and health behaviors.
4 We examined whether executive functions predict physical activity, sedentary activity, and
5 healthy and unhealthy diets, and whether trait self-control and self-control resources mediate
6 these associations. Three hundred and eighty-five participants completed a questionnaire
7 assessing trait self-control and self-control resources, physical activity, sedentary activity, and
8 healthy and unhealthy diets. They also performed three randomly ordered cognitive tasks, a
9 stop-signal task (i.e., inhibition), a letter memory task (i.e., updating), and a number-letter
10 task (i.e., switching). Structural equation modeling revealed that self-control resources
11 predicted positively physical activity ($R^2 = .08$), negatively sedentary activity ($R^2 = .03$) and
12 positively healthy diet ($R^2 = .10$). Moreover, trait self-control predicted positively healthy diet
13 ($R^2 = .10$) and negatively unhealthy diet ($R^2 = .19$). Moreover, analyses revealed that
14 switching significantly predicted self-control resources, and highlighted three totally mediated
15 relations between this executive function and physical activity, sedentary activity and healthy
16 diet. However, no evidence was found supporting associations between inhibition and
17 updating, and health behaviors, or relations mediated by self-control for these executive
18 functions. The findings suggest the importance of trait self-control and self-control resources
19 for health behavior adoption and pave the way for studies exploring the role of the executive
20 functions in an affective context. Open materials [<https://osf.io/hpsjw/>].

21

22 Keywords: self-control resources, trait self-control, inhibition, updating, switching, health
23 behaviors

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1. Introduction

According to the World Health Organization, physical inactivity and an unhealthy diet are among the most important risk factors for noncommunicable diseases, causing one death every seven seconds and one death every three seconds, respectively (Forouzanfar, Afshin, Alexander, Biryukov, et al., 2016; Lee et al., 2012). Changing these unhealthy behaviors by improving the regularity of physical activity and healthiness of diet could prevent 16 million premature deaths each year (Forouzanfar, Afshin, Alexander, Anderson, et al., 2016). Despite widespread declarations of intention to adopt healthy behaviors, most people fail to reach minimum recommendations (Ford et al., 2011). In this context, some promising conflict resolution models could effectively promote health behaviors (Sniehotta et al., 2014).

Conflict resolution models (e.g., the integrative self-control theory, Kotabe et Hofmann, 2015; the goal-conflict model, Stroebe, 2022) emphasize that health-behavior facilitators (e.g., health-behavior goals, such as an intention to do more physical activity) face barriers (e.g., temptation toward the competing behavior, such as a desire to engage in a sedentary activity), leading to motivational conflicts that need to be resolved (Forestier, et al., 2022a; Rabiau et al., 2006). An adaptative resolution of this conflict (i.e., one in favor of the goal) promotes the health-behavior goal (e.g., going for a run, snacking on an apple). A maladaptive one promotes the competing behavior (e.g., remaining on the couch, snacking on a chocolate bar) (e.g., Gillebaart et al., 2016). Here, self-control is defined as the self-regulation operationalization, by which an individual resolves a motivational conflict, through either an effortless or effortful strategy (Forestier et al., 2022b; Gillebaart, 2018). As such, it is expected to play a key role in promoting the resolution of motivational conflicts, favoring healthy behaviors. Indeed, some studies showed correlations between self-control and healthy diet and weight control with a small-to-medium effect size (de Ridder et al., 2012, $r = .17$), and self-control and physical activity (Pfeffer & Strobach, 2018, $r = .29$).

26 In 2018, Forestier et al. identified individual differences in trait self-control and self-
27 control resources, as two dimensions independently associated with health behaviors. Despite
28 their importance, self-control resources have been mostly considered in ego-depletion
29 research (e.g., Rouse et al., 2013; see Forestier et al., 2022 for more details) and rarely on
30 research on self-control and health behaviors (de Ridder et al., 2018). However, defined as
31 “the objective and subjective amounts of energy available for the self to initiate a self-control
32 act” (Forestier et al., 2022b, p. 21), the self-control resources seem crucial for motivational
33 conflict resolution, and can be assessed through subjective perception of energy availability,
34 or physiological markers (e.g., vagal activity). Accordingly, trait self-control distinguishes
35 individuals with a more or less tendency to successfully resolve motivational conflicts. In
36 parallel, individual differences in self-control resources distinguish individuals with a more or
37 less tendency to experience a high level of self-control resources (Forestier et al., 2018).
38 Authors identified that a remarkable portion of variance (40%) in self-control resources is
39 found at the between-person level (Smolders et al., 2013). In short, individuals with high trait
40 self-control consume a healthier diet than those with low trait self-control; individuals with
41 high self-control resources practice more physical activity, are less sedentary, and eat
42 healthier than individuals with low self-control resources. These results are in line with Finne
43 et al. (Finne et al., 2019), highlighting that within-person self-control fluctuations are more
44 important than between-person differences to predict physical activity. Moreover, a recent
45 study showed that within-person variations of self-control strength (i.e., a scale that could
46 refer to what Forestier et al., (2022) proposed as “self-control willingness”) predict physical
47 activity but not trait self-control (Englert & Rummel, 2016).

48 Despite these interesting results, Forestier et al. (2018) did not specifically examined
49 the predictors of individual differences in the two self-control dimensions. Some hypotheses
50 on the executive functions have been already put forward that can partly explain the

51 differences in these dimensions (e.g., Hofmann et al., 2012, Table 2). Specifically, inhibition,
52 updating and switching (also called “inhibitory control”, “working memory”, and “cognitive
53 flexibility” respectively) is likely related to self-control, and individuals with higher executive
54 abilities would, therefore, be good self-controllers (Friese et al., 2011; Hofmann et al., 2011).
55 Moreover, executive functions could operationalize the “self-control capacity” that makes
56 self-control success possible (Forestier, et al., 2022b; Kotabe & Hofmann, 2015). Presumably,
57 for instance, individuals with high inhibition capacity should present high self-control through
58 a better ability to override prepotent responses such as habits or impulses that are
59 incompatible with goals attainment. Likewise, individuals with high working memory
60 abilities could better maintain information in an active, quickly retrievable state and shield
61 this information from distraction. They are therefore better able to use goal-relevant
62 information. Finally, relative to individuals with lower switching ability, individuals with high
63 switching may present high self-control through a high flexibility (opposed to “rigidity”),
64 which allow goal attainment by abandoning suboptimal means and selecting alternative
65 means to reach the same goal (see Hofmann et al., 2011, 2012, for full theoretical discussion).
66 Additionally, structurally and functionally, brain networks in the prefrontal cortex that control
67 executive function, overlap with networks involved in self-control (e.g., right inferior frontal
68 gyrus, Cipolotti et al., 2016; Lopez et al., 2016).

69 Several assumptions on how executive functions and self-control might interact have
70 been proposed, including the mediation model hypothesis (Hofmann et al., 2012). To date,
71 most empirical self-control studies examined executive functions as moderators of the relation
72 between self-control and health behaviors (Hofmann et al., 2009a; Pfeffer & Strobach, 2017),
73 with mitigated results. Hence, we currently aimed at addressing the rarely explored approach
74 of executive functions as direct predictor of self-control. As far as we know, only Saunders et
75 al. (2018) and Necka et al. (2018) have investigated the association between executive

76 functions and self-control. Saunders et al. (2018) found no evidence of a correlation between
77 trait self-control and inhibition. Using structural equation modeling, Necka et al. (2018) found
78 no significant association between a “trait self-control” latent variable and an “executive
79 functions” latent variable. However, methodological improvement would allow some results-
80 related pitfalls to be avoided. First, only the relations between latent variables were tested,
81 without examining the independent contribution of each executive function to trait self-
82 control. Second, these previous studies never focused on self-control resources, which are
83 correlated with trait self-control but remain an independent dimension to be considered
84 (Forestier et al., 2018). Third, the possibility that trait self-control and executive functions are
85 associated with health behaviors was not investigated. Yet, the relation between executive
86 functions and health behaviors deserves attention. Indeed, another study showed that
87 individuals with the highest inhibition adopted a less unhealthy diet (Hofmann et al., 2009).
88 Similarly, high updating abilities have been associated with more physical activity
89 (Lambourne, 2006; Pfeffer & Strobach, 2017). Finally, a bi-directional relationship between
90 executive functions and health behavior has been proposed, with individuals with high
91 executive abilities being more likely to adopt a healthy lifestyle that would, in turn, enhance
92 their executive functions in the long run (Allan et al., 2016). Empirical data has recently been
93 reported supporting this relation (Cheval et al., 2020). Accordingly, if executive functions are
94 correlated with self-control, as advanced theoretically (Hofmann et al., 2012), they could
95 promote health behaviors through direct and indirect effects, partially mediated by trait self-
96 control and self-control resources. Such assumptions have never yet been tested.

97 The current study aimed to investigate the independent contribution of each executive
98 function to self-control and four crucial health behaviors to prevent noncommunicable
99 diseases, while considering differences among individuals in their trait self-control and self-
100 control resources. For these purposes, structural equation models were used, one for physical

101 activity versus sedentary activity, and a second for a healthy versus an unhealthy diet, as in
102 Forestier et al., (2018). In line with theoretical discussions (Hofmann et al., 2012), we
103 hypothesized that executive functions would positively predict trait self-control and self-
104 control resources (H1) and healthy behaviors (physical activity and healthy diet) (H2), and
105 negatively predict unhealthy behaviors (sedentary activity and unhealthy diet) (H3). Similarly,
106 we hypothesized that trait and self-control resources would positively predict healthy
107 behaviors (H4) and negatively predict unhealthy behaviors (H5). Finally, the mediated
108 relation implies that (H6) executive functions will be positively related to trait self-control
109 and self-control resources, which will in turn be related to health behaviors¹. Figure 1
110 summarizes our hypotheses.

111 2. Method

112 Overview

113 Participants were recruited via social media, personal mailing lists, and direct
114 advertising messages during classes. They were all students at sports and psychology faculties
115 of three different universities. Data were collected over three weeks (November 2021) by
116 completion of three cognitive tasks and four questionnaires on Inquisit web version 6.3.2.0
117 (Computer software) (data hosted by Inquisit, Europe repository) (during a single session
118 lasting 1h15). All procedures in this study complied with APA ethical principles. Informed
119 consent was obtained from all participants before the beginning of the study. It should also be
120 noted that the participants were informed that the online study was anonymous and
121 confidential: only a self-generated code allowed their identification.

¹No differential hypotheses regarding the role of trait self-control and self-control resources were formulated because of the rare existing evidences about relations between self-control resources and health behaviors. Moreover, we did not formulate differential hypotheses regarding the role of self-control and behaviors, because (a) despite differences, health behaviors considered share similarities (e.g., long-term benefits), as well as unhealthy behaviors share some (e.g., appetitive) (McEachan et al., 2010); and (b) literature stressed that self-control behave in comparable manner on different healthy (e.g., positive relation) and unhealthy behaviors (e.g., negative relation) (de Ridder et al., 2012).

122 **Participants and sample size**

123 Three procedures were used for estimating our sample size, and its relevance. The first
124 procedure aims to estimate a minimal sample size to reach. The second one aims to determine
125 a stopping rule to fix when data collection will end. The last one aims to compare the sample
126 size reached and the smallest detectable effect size with a certain power to what the literature
127 identified in past studies with common features, to consider whether another phase of data
128 collection is necessary or not. Precisely, first, we used a method specific to structural equation
129 modeling (MacCallum et al., 1996, 2006a; MacCallum & Hong, 1997) to estimate an a priori
130 minimum sample size to obtain a fit index, namely RMSEA, within a given range [0.00; 0.08]
131 (as recommended on the literature, Brown, 2015), with 90% power and $\alpha = .05$. Based on
132 simulations, the minimum sample size was $N = 26$ (data and code for this estimation are
133 available at https://osf.io/hpsjw/?view_only=6e28c8307294494e9eec45d2670efd8d)
134 (MacCallum et al., 2006b). Second, we estimated an a priori maximum sample size by using
135 the stopping rule based on resource constraints. Because we endorsed no priors regarding an
136 expected effect size, we decided to recruit as many participants as possible during the running
137 of the online study. During these three weeks, 535 people logged on. Exclusion criteria were
138 individuals who: (1) did not consent to participate; (2) completed the study multiple times; (3)
139 responded incorrectly to seriousness checks (Aust et al., 2013); (4) did not consider regular
140 physical activity and healthy diet as important for them (i.e., below 2 on a 1-7 goal-
141 importance scale, Fishbach et al., 2003). In addition, we used the *performance* package
142 (version 0.10.0) (Lüdecke et al., 2021) for R-Studio (R Core Team, 2021) to identify
143 observations that were influential on the nine variables of interest (see Measures section).
144 Specifically, based on a composite score obtained via the application of multiple outlier
145 detection algorithms (Lüdecke et al., 2021), we excluded participants classified as influential
146 by at least half of the methods used by this package (the data and code of this data cleaning

147 are available at https://osf.io/hpsjw/?view_only=6e28c8307294494e9eec45d2670efd8d). The
148 application of these exclusion criteria in the described order led to a final sample size of $N =$
149 385 participants (154 women; $M_{\text{age}} = 19.42$, $SD_{\text{age}} = 2.71$).

150 Finally, we conducted a sensitivity power analysis with G*Power 3.1.9.4 (Faul et al.,
151 2007) to estimate the minimal effect size on the most constrained multiple regression of the
152 structural equation models. With our convenience sample of $N = 385$, $n_{\text{predictors}} = 5$ (see
153 Measures), power = .90, $\alpha = .05$, the smallest detectable effect size was $f^2 = .04$. This is one of
154 the smallest small-to-medium effect sizes (range = .02 to .15), in line with findings on the
155 relationships between self-control and health behaviors (Pfeffer & Strobach, 2018).

156 **Measures**

157 *Independent Variables*

158 **Inhibition**

159 A recent consensual stop-signal task² (Verbruggen et al., 2019) was used to assess
160 inhibition. The task included 216 trials in total, splitted in 3 blocks of 72 trials. A typical trial
161 started with a central fixation circle presented for 250 ms, followed by display of the stimulus
162 (a right- or left-pointing white arrow within a circle) until the participant's response. The
163 instruction was to respond systematically according to the direction indicated by the arrow by
164 pressing a predefined keyboard button. However, participants had to stop their response (i.e.,
165 not press the key) if a signal beep was made after the presentation of the arrow. The delay
166 between the arrow's presentation and the beep was adjusted up or down by 50 ms as a
167 function of the participant's performance, starting with an initial delay of 250 ms. The delay

²We preferred the stop-signal task for inhibition because it has been proposed as more closely related to self-control, as it captures more specifically behavioral control, compare to other task such as the Stroop task (supposedly more associated with cognitive inhibition) (Diamond, 2013). We preferred the letter-memory task for updating, because it was the most strongly associated with "updating" latent factor on Miyake et al., (2000) and Miyake & Friedman (2012). We preferred the number-letter task for updating, because it has been proposed as one of the more reliable, and as more appropriate for adults than other task (Diamond, 2013).

168 could be increased up to 1150 ms if the previous signal-stop was successful, and decreased
169 down to 50 ms if the previous signal stop failed. This delay is referred to as the Stop-Signal
170 Reaction Time (SSRT) and gives an estimation for response-inhibition latency in
171 milliseconds. We calculated the SSRT by using the integration method (Verbruggen et al.,
172 2019). The lower the SSRT, the more difficult it is to stop the go-process, and the higher the
173 SSRT, the easier it is to stop the go-process. Accordingly, a lower (higher) SSRT integration
174 means the participant has stronger (weaker) inhibition.

175 **Updating**

176 We used a letter memory task to measure updating² (Friedman et al., 2008). A series
177 of letters appeared consecutively in the center of the screen for a duration of 2.5 s for each
178 letter. Written instructions asked participants to recall, in forward order, the last three letters
179 after the last letter's disappearance, by selecting the correct letters from a letter matrix
180 provided. They had to click "blank" if they skipped a particular letter. The number of letters
181 per series varied randomly through time (5, 7, or 9 letters). In total, 12 measurement trials
182 were completed (four of each length). Answers were scored as correct even if the three letters
183 were not recalled in the correct order (Miyake et al., 2000). The more participants were able
184 to recall letters per trial, the better their updating was considered.

185 **Switching**

186 Switching was assessed with a number-letter task² (Miyake et al., 2000). This task
187 involves two categorization tasks, in which character pairs including a letter and a number
188 (e.g., 3T, 4A) were presented. The participants were asked to categorize the pair depending on
189 whether the letter was a consonant or vowel (i.e., letter task), or depending on whether the
190 number was odd or even (i.e., number task). The tasks alternated between categorizing rules
191 in a clockwise fashion, and thus used predictable location cues in a 2x2 matrix (i.e., the top of
192 the matrix for letter categorization and bottom of the matrix for number categorization). Odd-

193 numbered trials were set as “switch task” trials and even-numbered trials as “non-switch task”
194 trials. Participants responded by button press, and the next stimulus was presented 150 ms
195 after the response. The whole task was composed of 128 trials. The reaction time switch cost
196 was calculated by assessing the difference between the correct latency of switch trials and
197 non-switch trials (Miyake et al., 2000). A positive reaction time switch cost indicates a slower
198 response in switch trials, than in non-switch trials, and conversely. For example, a highly
199 positive reaction time switch cost indicates low switching. Trials with reaction times under
200 150 ms and above 2000 ms were excluded from analyses (Rossell & Nobre, 2004;
201 Schoonbaert et al., 2011).

202 *Mediating Variables*

203 **Trait Self-Control**

204 Trait self-control was assessed with the 13-item version of the Brief Self-Control Scale
205 (Tangney et al., 2004). Participants responded to the following instruction: “For each
206 sentence, choose what suits you best”, on a 7-point Likert scale from 1 (*Don't agree at all*) to
207 7 (*Completely agree*), with regard to the different items ($\alpha = .80$, $\omega = .83$).

208 **Self-Control Resources**

209 Self-control resources were assessed by the subjective vitality scale, as in previous
210 studies (Forestier et al., 2018). Participants were asked to answer the 5-item questionnaire
211 (e.g., “At the moment, I feel alive and full of vitality”), with the following instruction: “For
212 each item, please indicate the general feeling you have experienced over the past 7 days, by
213 selecting the most appropriate number” on a 7-point Likert scale from 1 (*Don't agree at all*)
214 to 7 (*Completely agree*) ($\alpha = .89$, $\omega = .92$).

215 *Dependent Variables*

216 **Physical Activity and Sedentary Activity**

217 Physical activity and sedentary activity were measured using the International Physical
218 Activity Questionnaire (Craig et al., 2003). Participants were asked to indicate how much
219 time they had spent doing moderate-intensity and vigorous-intensity physical activities (i.e.,
220 MVPA), how much time they had spent walking, and how much time they had spent sitting
221 and/or lying down (i.e., sedentary activity) in minutes, in their daily life over the last 7 days.

222 **Healthy and Unhealthy Diet**

223 Healthy and unhealthy diets were assessed using the Healthy Eating Behavior Scale
224 (Pelletier et al., 2004), composed of two subscales: four items related to a healthy diet (e.g., “I
225 eat fruit and vegetables”) and the remaining items related to an unhealthy diet (e.g., “I use
226 white sugar”). Participants indicated their consumption frequency on a 7-item scale ranging
227 from 1 (*once or twice per month*) to 7 (*more than three times per day*).

228 **3. Results**

229 Descriptive statistics and Pearson’s correlation coefficients are provided in the
230 Supplementary Materials (Tables S1 and S2). Correlations’ table revealed that self-control
231 resources are significantly correlated with trait self-control ($r = .21$), MVPA ($r = .27$),
232 sedentary time ($r = -.14$), healthy diet ($r = .15$), unhealthy diet ($r = -.12$) and switching ($r = -$
233 $.13$). It also stresses that trait self-control is only significantly correlated with healthy and
234 unhealthy diet ($r = .21$ and $r = -.27$, respectively). The only behaviors significantly correlated
235 are MVPA and healthy diet ($r = .25$). Among executive functions scores, switching is
236 significantly correlated with MVPA ($r = -.10$), and inhibition with healthy diet ($r = -.10$).

237 **Structural Equation Modelling**

238 *Analytical Strategy*

239 The hypotheses were tested using structural equation modeling with the *Lavaan* package
240 (version 0.6-8, Rosseel, 2012) in R-Studio (RStudio Team, 2015) (the R script, raw data, and
241 analysis dataset can be found in the Open Science Framework, at
242 https://osf.io/hpsjw/?view_only=6e28c8307294494e9eec45d2670efd8d). We used a two-step
243 approach (Anderson & Gerbing, 1988). The first step is a confirmatory factor analysis (CFA).
244 Hence, we verified the construct validity of the measurement model to estimate a reliable one,
245 by examining factor loadings, modification indices and model fit indices. Second, after a
246 satisfactory fit was achieved for the measurement model, we tested the structural model (i.e.,
247 the hypothesized relationships between the variables). The results section presents only the
248 structural models (see Measurement Models in Supplementary Materials). Model fit was
249 assessed by examining the comparative fit index (CFI), Tucker–Lewis Index (TLI), and root-
250 mean-square error of approximation (RMSEA), with a satisfactory model having a CFI and a
251 TLI over 0.90, a RMSEA below 0.05 (Brown, 2015). Finally, after an estimation of the full
252 hypothetical model, non-significant paths were removed to estimate model’s parsimony
253 reliability (MacCallum & Austin, 2000). The statistical significance was set at $\alpha = .05$. Data
254 were standardized prior to model estimation. Indirect effects (i.e., mediation) were estimated if
255 independent variables and mediators were significantly associated with the dependent
256 variables, with the *RMediation* package (version 1.2.0) (Tofighi & MacKinnon, 2011).

257 *Physical Activity and Sedentary Activity Structural Model*

258 The physical activity and sedentary activity structural model contained two latent
259 variables (trait self-control and self-control resources) and five observed variables (inhibition
260 score, updating score, switching score, MVPA score, and sedentary activity). Moreover,
261 compared with the measurement model, we added covariances between the three executive

262 function scores. The full structural equation model yielded good model-fit indices (χ^2 (130) =
263 153.43, RMSEA = 0.02, 90% CI [0.00, 0.03], CFI = 0.99, TLI = 0.99). Partially confirming
264 our hypothesis (H1), only one of the three executive function scores considered was
265 significantly associated with self-control. Precisely, switching was negatively related to self-
266 control resources ($\beta = -.10$, 95% CI [-.18, -.01], $p = .02$, $R^2 = .02$), evidencing that the higher
267 the cost, the lower the self-control resources. Contrary to our hypotheses (H2, and H3),
268 executive function scores were not significantly associated with physical activity and
269 sedentary activity (i.e., no direct effect). In partial accordance with H4 and H5, only self-
270 control resources positively predicted MVPA ($\beta = .31$, 95% CI [.18, .43], $p < .001$, $R^2 = .08$)
271 and negatively predicted sedentary activity ($\beta = -.17$, 95% CI [-.30, -.05], $p = .01$, $R^2 = .03$).
272 Trait self-control was not significantly associated with healthy or unhealthy behaviors.
273 Mediation analysis revealed a significant indirect effect of switching on physical activity
274 (*indirect* = -.03, 95% CI [-.06, -.00], $p = .02$) and sedentary activity (*indirect* = .02, 95% CI
275 [.00, .04], $p = .03$), suggesting total mediations through self-control resources, which partially
276 confirm our hypothesis (H6). Figure 2 shows this structural model³.

277 ***Healthy and Unhealthy Diet Structural Model***

278 The healthy and unhealthy diet structural model contained four latent variables (trait
279 self-control and self-control resources, and healthy and unhealthy diet scores), three observed
280 variables (i.e., inhibition, updating, and switching scores), and the covariances between the
281 three executive function scores. The full structural equation model yielded good model-fit
282 indices (χ^2 (188) = 218.35, RMSEA = 0.02, 90% CI [0.00, 0.03], CFI = 0.99, TLI = 0.99).
283 Switching was still associated with self-control resources, as in the physical and sedentary
284 activity model. Contrary to H2, and H3, there was no significant direct association between

³For exploratory purpose, we conducted the model separately on vigorous and moderate physical activity, and on walking. Tables of these models are in Supplementary Materials (S5, S6, S7)

285 executive functions with healthy and unhealthy diets. Mostly according with H4 and H5,
286 results revealed that trait self-control positively predicted healthy diet ($\beta = .28$, 95% CI [.07,
287 .50], $p = .01$, $R^2 = .10$) and negatively predicted unhealthy diet ($\beta = -.64$, 95% CI [-.91, -.36],
288 $p < .001$, $R^2 = .19$), and that self-control resources also positively predicted healthy diet ($\beta =$
289 .13, 95% CI [.02, .23], $p = .02$, $R^2 = .10$). Mediation analysis revealed a significant indirect
290 effect of switching on healthy diet (*indirect* = -.01, 95% CI [-.03, -.00], $p = .02$), suggesting a
291 total mediation through self-control resources. This partially confirms H6. Figure 3 shows this
292 structural model. Table 3 summarizes regression coefficients of the two structural models (the
293 complete tables are available in the Supplementary Materials, Tables S3 and S4).

294 4. Discussion

295 The present study tested the role of executive functions as predictors of individual
296 differences in trait self-control and self-control resources, which are likely also associated
297 with health behaviors (physical activity, healthy diet, sedentary activity, and unhealthy diet).
298 Partially contrary to our hypotheses, we found small evidence supporting the role of executive
299 functions as predictors of individual differences in trait self-control or self-control resources.
300 Precisely, switching was only associated with self-control resources. Similarly, no direct role
301 of these functions regarding healthy and unhealthy behaviors was observed. Nevertheless, in
302 support of our hypotheses, there was an association between individual differences in self-
303 control and health behaviors. Individuals with higher self-control resources practiced more
304 physical activity, ate healthier, and spent less time being sedentary than individuals with
305 lower self-control resources. It also indicated that individuals with higher trait self-control
306 adopted a healthier diet, and a less unhealthy one, than individuals with lower trait self-
307 control. These findings stress the central role of self-control, and especially of self-control
308 resources, for adopting health behaviors. Finally, we observed three indirect effects of
309 switching on behaviors, totally mediated by self-control resources. Individuals with higher

310 switching were more physically active, less sedentary, and ate healthier, through higher self-
311 control resources. These findings pave the way to a more refined understanding of the
312 predictors of individual differences in self-control resources, and to the ways by which
313 executive functioning could influence health behaviors.

314 *Relations Between Executive Functions, Self-Control, and Health Behaviors*

315 Partially according with Necka et al. (2018) and Saunders et al. (2018), our study did not find
316 strong evidence of significant associations between executive functions and self-control.
317 However, our intention was to examine the contribution of each executive function to self-
318 control and health behaviors. Indeed, it was proposed that updating and inhibition might be
319 the most important executive functions for self-control, enabling a better representation of the
320 goal and a better inhibition for fighting a threatening temptation (Hofmann et al., 2012).
321 However, our study does not support these suggestions.

322 Suggestions were divided concerning the role of switching. On the one hand, , when
323 facing a motivational conflict, individuals with high switching could efficiently switch from
324 an ineffective conflict resolution strategy (e.g., resisting temptation) to a situationally more
325 effective (e.g., avoiding temptation) (Hofmann et al., 2012). On the other hand, individuals
326 with high switching could present lower self-control as this switching could promote quick
327 and efficient disengagement from a goal-oriented mindset to a mindset oriented toward the
328 pursuit of tempting alternatives (Hofmann et al., 2012). Our results support partially the first
329 statement. Individuals with high switching are more likely to be able to shift their mind
330 toward subjective feelings permitting goal-attainment strategies, such as high self-control
331 resources, useful for efficient self-control act and adaptative motivational-conflict resolution.

332 Our findings also support the absence of evidence in favor of direct relations between
333 executive functions, trait self-control and physical activity, as observed in some previous
334 studies. Pfeffer and Strobach (2017) showed that most composite executive functions scores

335 they calculated were not significantly correlated with trait self-control, except for two
336 switching scores that were, modestly (i.e., task-cueing $R^2 = .04$, alternating-runs $R^2 = .03$;
337 Pfeffer & Strobach, 2017). They also revealed that most executive function scores were not
338 significant direct predictors of intention-behavior gap, except for updating score. These
339 findings highlighted no direct relations either between executive functions and trait self-
340 control or between executive functions and a physical activity, which is consistent with the
341 current results. Interestingly, Pfeffer et Strobach (2017) found that half of the executive-
342 function scores they considered (one inhibition, one updating, and one switching score)
343 moderated the effects of trait self-control on the physical activity intention-behavior gap.
344 Together with our results, this suggests that updating and inhibition are not direct predictors
345 of individual differences in self-control and physical activity, but could rather moderate the
346 relation between self-control and this behavior. However, because the other half of the
347 executive-function scores they considered (one inhibition score, one updating score, and one
348 switching score) showed no interaction with self-control to predict physical activity, further
349 investigations are required.

350 Similarly, the fact that we found no significant direct relations between executive
351 functions and unhealthy diet were consistent with Hofmann et al. (2009). Indeed, there study
352 stressed no direct correlation between candy consumption and different components of
353 inhibition, but these latest (i.e., executive attention, behavioral inhibition, affect regulation)
354 consistently moderated the relations between automatic affective reactions and candy
355 consumption. All other things being equal, our study and the aforementioned results
356 (Hofmann et al., 2009; Necka et al., 2018; Pfeffer & Strobach, 2017) taken together suggest
357 that inhibition and updating are not direct predictors of self-control or healthy or unhealthy
358 behaviors, but could moderate relations between affective reactions (e.g., automatic affective
359 reactions, conscious experience of temptations) and behaviors, and between self-control and

360 health behaviors. Investigations of inhibition and updating as moderators of the relation
361 between self-control and health behaviors would be of particular interest.

362 *Relations Between Self-Control and Health Behaviors*

363 All the relations found between self-control and health behaviors are consistent with
364 the literature (de Ridder et al., 2011, 2012; Forestier et al., 2018). Specifically, self-control
365 resources were related to physical activity, sedentary activity, and healthy diet, while trait
366 self-control was significantly related only to healthy and unhealthy diet. Furthermore, self-
367 control aspects have different effects depending on the behavior examined, with quite a
368 similar effect size previously estimated (Forestier et al., 2018). Precisely, self-control
369 resources were related to health behaviors with a descriptively comparable effect size (i.e., R^2
370 = .08 for physical activity, and $R^2 = .10$ for healthy diet) and a smaller effect size for the
371 unhealthy behavior ($R^2 = .03$). It suggests that self-control resources are likely efficient to
372 promote health behaviors, but less effective in preventing the unhealthy ones. Health
373 behaviors show differences as well as similarities. For example, physical activity, and a
374 healthy diet are comparable as they require to be initiated, while sedentary activity and an
375 unhealthy diet are both things that need to be stopped (McEachan et al., 2010). Nevertheless,
376 physical activity requires more effort to be initiated than a healthy diet (McEachan et al.,
377 2010), and sedentary activities appear to be attractive because they preserve energy
378 expenditure (Cheval & Boisgontier, 2021), while unhealthy food seems attractive because of
379 the immediate pleasure it provides (Appelhans, 2009; Volkow et al., 2011). Another
380 interesting perspective could be to investigate the influence of behavioral features on self-
381 control aspects that could be effective or ineffective in the conflict resolution. This
382 encouraging finding requires further investigations, for example with other studies' design
383 (see "Strengths, Limitations, and Future Work Perspectives"), or with other instruments to
384 capture the behaviors, such as accelerometers for physical and sedentary activities, and daily

385 diet diary or questionnaires such as the new Healthy and Unhealthy Eating Behavior Scale
386 (Guertin et al., 2020) for diet behavior, to confirm the crucial role of self-control resources for
387 health behaviors.

388 **Strengths, Limitations, and Future Work Perspectives**

389 Several limitations of the present study need to be addressed. First, our study sample
390 consisted of young and relatively healthy students. Psychological determinants driving
391 behavior maintenance could differ from those driving behavior change (e.g., habit vs. coping
392 planning). Hence the current results need to be replicated in individuals engaged in health
393 behavior change processes. Second, the cross-section of the current study is insufficient to
394 understand the role of within-person variations in executive functions and self-control in daily
395 fluctuations of health behaviors. Nevertheless, the within-person variations of inhibition seem
396 more predictive of snack consumption (i.e., unhealthy diet) than individual differences in
397 inhibition (Powell et al., 2017). In addition, an important part of the variance of self-control
398 resources is found at the within-person level (i.e., 60%) despite variance at the between-
399 person level (Smolders et al., 2013). Thus, longitudinal study designs with daily repeated
400 measures will be required to properly examine the relationships of within-person executive
401 functions and self-control resource variations with health behavior fluctuations. Third, our
402 study considered executive functions and self-control as predictors of the overall level of
403 health behaviors over a week, without measuring the participant's intention to engage in these
404 behaviors. Despite including only individuals who considered physical activity and healthy
405 diet important for them, it remains possible that they did not support a particular intention to
406 engage in healthy behaviors during the week we considered. For example, some participants
407 may not have practiced physical activity because they did not intend to, rather than because of
408 low self-control. Future studies could assess intention-behavior gap instead of health
409 behaviors' global level over a week. In line with previous studies (Pfeffer et al., 2020; Pfeffer

410 & Strobach, 2017), participants could be asked their intention to engage in a certain quantity
411 of physical activity, to avoid a certain quantity of sedentary activity, to adopt a healthy diet,
412 and to avoid unhealthy food before and after all the measurements. Then the discrepancy
413 between intention endorsed and behaviors actually adopted (i.e., intention-behavior gap)
414 could be assessed to examine the role of executive functions and self-control in reducing this
415 gap. Finally, the self-reported nature of the self-control and behaviors measures is probably
416 another limitation of our study. As significant associations were observed between certain
417 self-reported measures (e.g., self-control resources and physical activity), we cannot exclude
418 that a part of these associations was because of a common method bias. However, we also
419 observed association between reaction-time task and self-reported measures (e.g., updating
420 and self-control resources), and also evidenced absence of significant association between
421 other self-reported measures (e.g., trait self-control and behaviors). Though, these specific
422 associations could rather suggest meaningful associations rather a method artifact. Altogether,
423 direct and conceptual (e.g., different measures and sample) replications could provide
424 valuable information, and identify the robustness of current (un)significant relations.

425 This study, nevertheless, has several strengths. We first examined the relative and
426 distinct role of the three executive functions, namely inhibition, updating, and switching, by
427 using executive tasks according to recent literature (e.g., Verbruggen et al., 2019). We also
428 tested our hypotheses with structural equation modeling, which increases the reliability of
429 scores and relations by (a) explicitly assessing the measurement error; (b) estimating latent
430 variable scores by scoring observed variables rather than other aggregating methods; and (c)
431 testing a model where a structure (e.g., covariances) could be imposed and assessed as to fit
432 of the data (Novikova et al., 2013). The final strength of our study is its good power to detect
433 small effect size (i.e., power = .90 for $f^2 = .04$).

434 **Conclusion**

435 No evidence was found supporting executive functions as direct predictors of the four
436 health behaviors considered. However, the current results support the role of self-control
437 resources as a potential way to promote physical activity and reduce sedentary activity, and
438 trait self-control as a likely determinant to increase adoption of a healthy diet and lower that
439 of an unhealthy diet. In sum, we hypothesize that *cold* executive functions may not explain
440 individual differences in self-control or health behaviors, and that the aspects of self-control
441 (trait or state) that are effective in health behavior adoption depend on the behavioral domain.
442 This study paves the way to longitudinal studies at the within-person level assessing the
443 effects of *hot* “affective-related” executive functions on trait and self-control resources and
444 health behaviors. Those effects can be tested by using affectively-charged executive function
445 in which the neutral stimuli (e.g., arrows, letter or number) are replaced by affective stimuli
446 such as pictograms of physical or sedentary activity, or of healthy or unhealthy food (e.g., see
447 Forestier et al., 2022b, p. 27-28, for a discussion). They can also be tested by using self-
448 control measures specific to the behaviors considered (e.g., self-control resources for
449 resolving physical-activity related motivational conflict).

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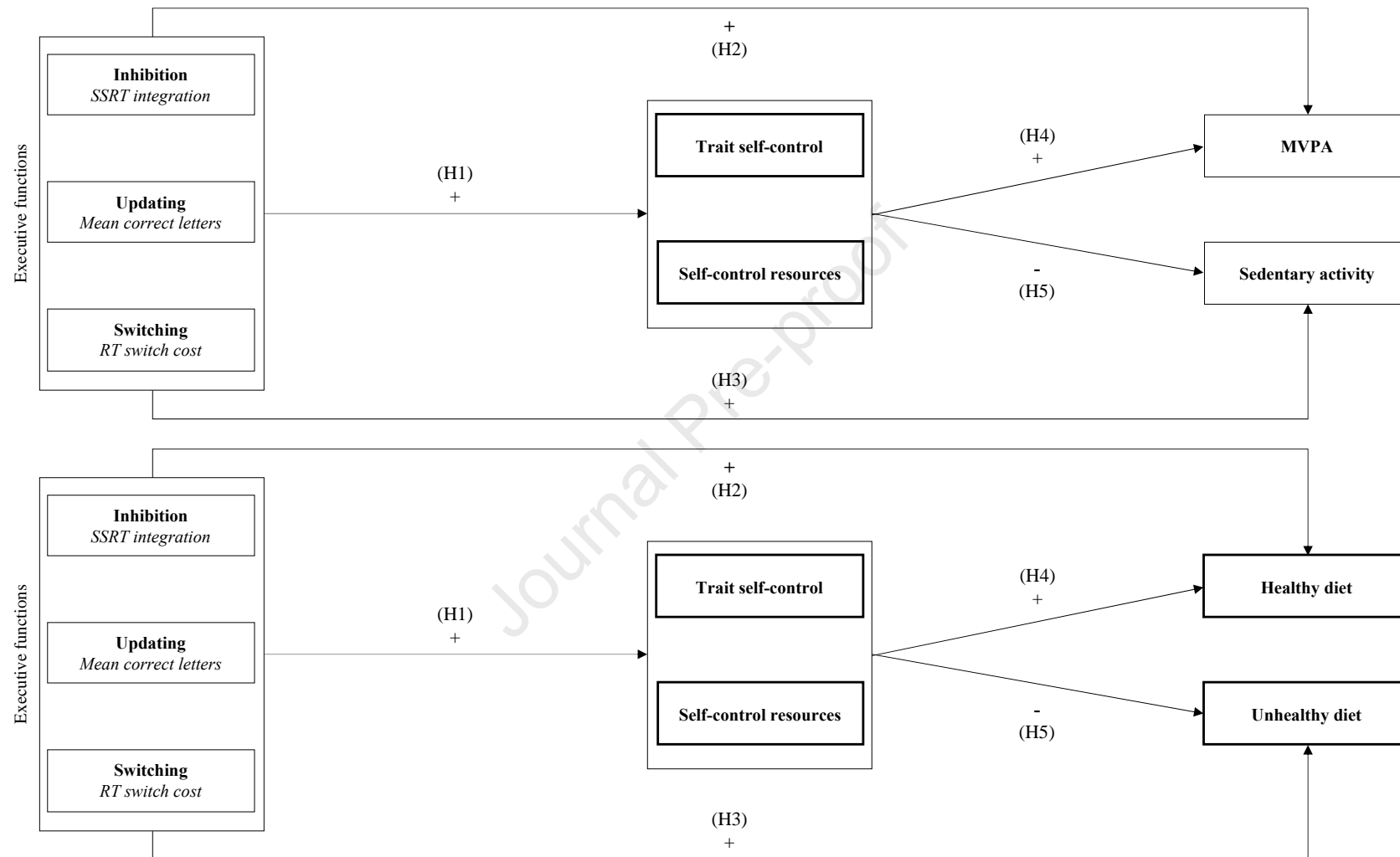
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Table 1*Regression Coefficients from Structural Equation Models*

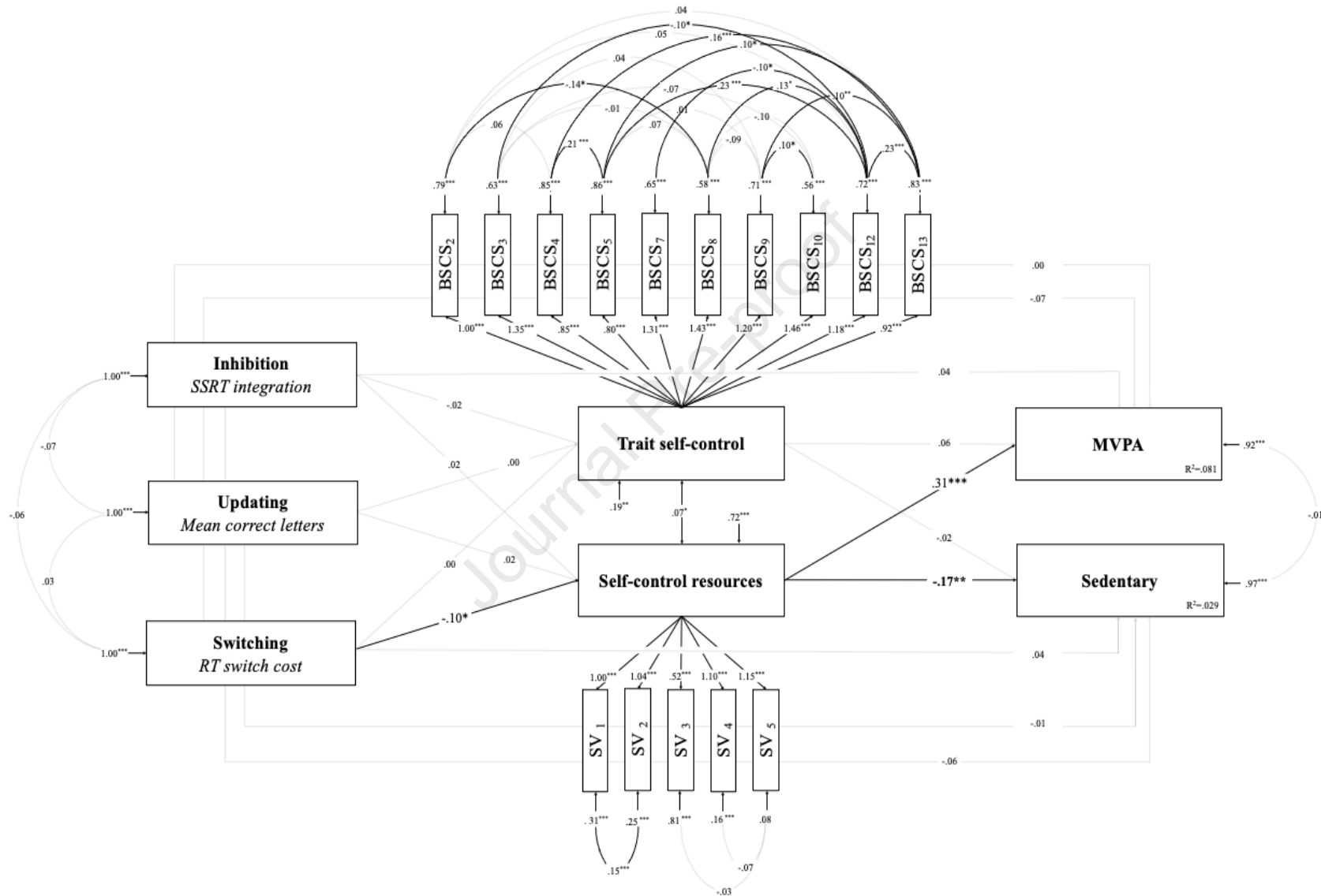
| Physical Activity and Sedentary Time Model | | | | | | | |
|---|---------------------------|----------------|-------------------------------|--------------|--------------|-------------|----------------|
| Independent variable | Dependent variable | Estimate | Estimate 95%CI [LL, UL] | Std. Err. | z | p | R ² |
| <i>Regression Slopes</i> | | | | | | | |
| SSRT integration (I) | Self-control resources | 0.02 | [-0.06, 0.11] | 0.04 | 0.58 | .562 | .015 |
| Mean correct letters (U) | | 0.02 | [-0.06, 0.10] | 0.04 | 0.47 | .638 | |
| RT switch cost (S) | | -0.10* | [-0.18, -0.01] | 0.04 | -2.27 | .023 | |
| SSRT integration (I) | Trait self-control | -0.02 | [-0.06, 0.03] | 0.03 | -0.61 | .541 | .001 |
| Mean correct letters (U) | | 0.00 | [-0.04, 0.05] | 0.02 | 0.18 | .860 | |
| RT switch cost (S) | | 0.00 | [-0.04, 0.05] | 0.02 | 0.20 | .842 | |
| SSRT integration (I) | MVPA | 0.04 | [-0.06, 0.14] | 0.05 | 0.81 | .418 | .081 |
| Mean correct letters (U) | | 0.00 | [-0.09, 0.10] | 0.05 | 0.10 | .924 | |
| RT switch cost (S) | | -0.07 | [-0.17, 0.03] | 0.05 | -1.44 | .150 | |
| Self-control resources | | 0.31*** | [0.18, 0.43] | 0.06 | 4.83 | .000 | |
| Trait self-control | | 0.06 | [-0.18, 0.30] | 0.12 | 0.51 | .609 | |
| SSRT integration (I) | Sedentary activity | -0.06 | [-0.16, 0.04] | 0.05 | -1.11 | .266 | .029 |
| Mean correct letters (U) | | -0.01 | [-0.11, 0.09] | 0.05 | -0.27 | .790 | |
| RT switch cost (S) | | 0.04 | [-0.06, 0.14] | 0.05 | 0.77 | .441 | |
| Self-control resources | | -0.17** | [-0.30, -0.05] | 0.06 | -2.71 | .007 | |
| Trait self-control | | -0.02 | [-0.27, 0.23] | 0.13 | -0.16 | .874 | |
| <i>Fit Indices</i> | | | | | | | |
| χ^2 | | 153.43 | | | | | |
| χ^2_{df} | | 130.00 | | | | | |
| p_ χ^2 | | .079 | | | | | |
| CFI | | .99 | | | | | |
| TLI | | .99 | | | | | |
| RMSEA | | .02 | [0.00, 0.03] | | | | |

| Healthy and Unhealthy Diet Model | | | | | | |
|---|------------------------|-----------------|-----------------------|-------------|--------------|-------------|
| <i>Regression Slopes</i> | | | | | | |
| SSRT integration (I) | Self-control resources | 0.03 | [-0.06, 0.11] | 0.04 | 0.58 | .559 |
| Mean correct letters (U) | | 0.02 | [-0.06, 0.11] | 0.04 | 0.49 | .627 |
| RT switch cost (S) | | -0.10* | [-0.18, -0.01] | 0.04 | -2.28 | .023 |
| SSRT integration (I) | Trait self-control | -0.02 | [-0.07, 0.03] | 0.03 | -0.61 | .542 |
| Mean correct letters (U) | | 0.00 | [-0.05, 0.05] | 0.03 | 0.18 | .856 |
| RT switch cost (S) | | 0.01 | [-0.04, 0.06] | 0.03 | 0.24 | .813 |
| SSRT integration (I) | Healthy diet | -0.07 | [-0.16, 0.01] | 0.04 | -1.76 | .078 |
| Mean correct letters (U) | | 0.07 | [-0.01, 0.16] | 0.04 | 1.73 | .084 |
| RT switch cost (S) | | 0.06 | [-0.02, 0.14] | 0.04 | 1.41 | .159 |
| Self-control resources | | 0.13* | [0.02, 0.23] | 0.05 | 2.34 | .019 |
| Trait self-control | | 0.28** | [0.07, 0.50] | 0.11 | 2.62 | .009 |
| SSRT integration (I) | Unhealthy diet | 0.02 | [-0.07, 0.12] | 0.05 | 0.47 | .637 |
| Mean correct letters (U) | | -0.02 | [-0.11, 0.08] | 0.05 | -0.33 | .743 |
| RT switch cost (S) | | -0.07 | [-0.16, 0.03] | 0.05 | -1.36 | .174 |
| Self-control resources | | -0.09 | [-0.21, 0.02] | 0.06 | -1.55 | .121 |
| Trait self-control | | -0.64*** | [-0.91, -0.36] | 0.14 | -4.56 | .000 |
| <i>Fit Indices</i> | | | | | | |
| χ^2 | | 218.35 | | | | |
| χ^2_{df} | | 188.00 | | | | |
| p_{χ^2} | | 0.06 | | | | |
| CFI | | 0.99 | | | | |
| TLI | | 0.98 | | | | |
| RMSEA | | 0.02 | [0.00, 0.03] | | | |

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. MVPA = Moderate to vigorous physical activity, SSRT = Stop-Signal Reaction Time, I = Inhibition, U = Updating, S = Switching

Figure 1*Hypothetical Models*

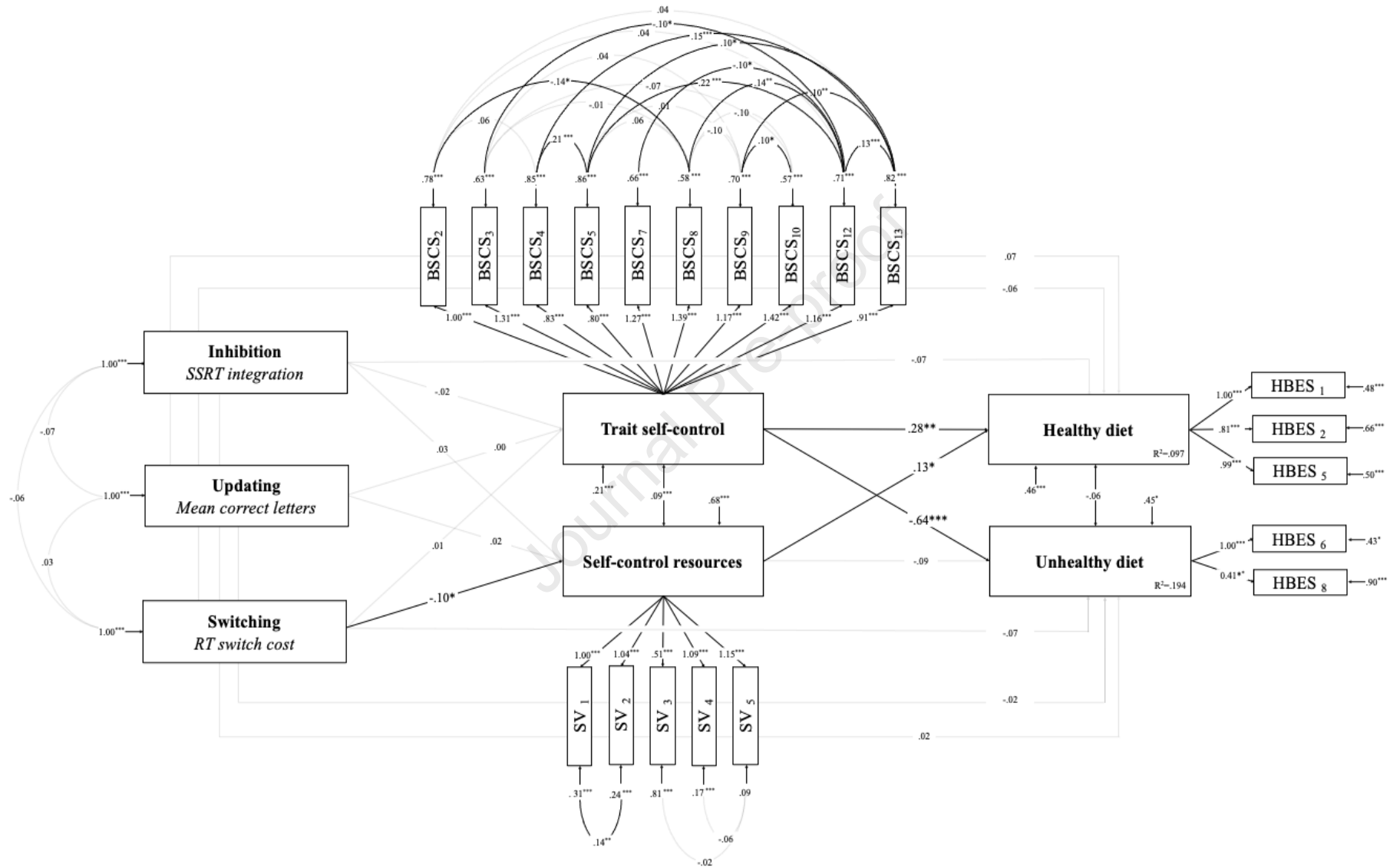
Note. These are summarized hypothetical models. The full model will test the relations between each executive function, trait and state self-control and each behavior. RT = Reaction Time, SSRT = Stop-Signal Reaction Time, MVPA = Moderate to Vigorous Physical Activity. Variables with a bold line are latent. Variables with normal line are observed. H6 is the hypothesis related to the effects of executive functions on health behaviors mediated by self-control and is not illustrated

Figure 2*Physical Activity and Sedentary Activity Full Structural Model*

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. SSRT = Stop-Signal Reaction Time, RT = Reaction Time, BSCS = Brief Self-Control Scale, SV = Subjective Vitality, MVPA = Moderate to Vigorous Physical Activity. Path darkness level distinguishes significant and non-significant relations.

Figure 3

Healthy and Unhealthy Diet Full Structural Model



Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. SSRT = Stop-Signal Reaction Time, RT = Reaction Time, BSCS = Brief Self-Control Scale, SV = Subjective Vitality, HBES = Healthy Eating Behavior Scale. Path darkness level distinguishes significant and non-significant relations.

- 1 • Trait self-control and self-control resources are associated with health behaviors
- 2 • Executive functions could have an effect on self-control and health behaviors
- 3 • Self-control resources predicted physical / sedentary activities and healthy diet
- 4 • Trait self-control predicted healthy and unhealthy diet
- 5 • Hot executive functions (affectively charged) seem promising for self-control

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The authors declare no conflict of interests.

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