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Lange, F. et al (2014). Turn It All You Want: Still No Effect of Sugar Consumption on Ego Depletion. *Journal of European Psychology Students, 5*(3), 1-8, DOI: http://dx.doi.org/10.5334/jeps.cc

RESEARCH ARTICLE

Turn It All You Want: Still No Effect of Sugar Consumption on Ego Depletion

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After having completed an initial self-control task, individuals typically show less self-controlled behavior on a consecutive task. In addition, this so-called ego-depletion effect is assumed to be alleviated by the consumption of sugar-containing drinks. However, a recent replication study indicates that this effect has been substantially overestimated. In contrast to mainstream ego-depletion research, initial and consecutive self-control tasks were identical in that study. Here we evaluate the generalizability of these results by testing 70 participants on a dual-task paradigm involving dissimilar tasks. Between self-control tasks, participants consumed a drink containing either sugar or an artificial sweetener. Results suggest that sugar consumption does not counteract ego depletion even when dissimilar self-control tasks are used.

Keywords: self-control; ego depletion; sugar consumption; replication; strength model

Following initial demonstrations of ego depletion by Baumeister and colleagues (Baumeister, Bratlavsky, Muraven, & Tice, 1998; Muraven, Baumeister, & Tice, 1999) a large number of empirical studies have generated evidence in support of a folk psychological notion: the human capacity to override habitual responses, impulses, thoughts and emotions is limited. According to the strength model of self-control (Baumeister, Vohs, & Tice, 2007), all acts requiring self-control draw on a common resource and self-control performance is determined by the current level of this resource. Hence, individuals are expected to perform more poorly on a self-control task after their resource has been depleted by a previous self-control task (Muraven & Baumeister, 2000). This ego-depletion hypothesis has been subject to multiple empirical tests adopting the dual-task paradigm (Hagger, Wood, Stiff, & Chatzisarantis, 2010). A recent meta-analysis of 83 studies reported a medium-to-large effect size for ego depletion on self-control performance on a consecutive task (Hagger et al., 2010). Moreover, studies by Gailliot et al. (2007) suggested that self-control strength is more than a metaphorical resource. Specifically, their results indicated that decreased performance on a second self-control task is associated with decreases in blood glucose and that supplementing glucose, but not artificial sweetener, counteracts the ego-depletion effect. This latter finding has been replicated several times (DeWall, Baumeister, Gailliot, & Maner, 2008; Gailliot, Peruche, Plant, & Baumeister, 2009; Masicampo & Baumeister, 2008; Wang & Dvorak, 2010). The meta-analysis by Hagger et al. (2010) yielded a large moderating effect ($d = 0.75$) of experimental glucose administration on the relationship between depletion and performance on a subsequent self-control task. Given these results, it has been concluded that self-control is fueled by blood glucose as a limited physiological resource (Gailliot et al., 2007). However, there are at least three lines of critique rendering this inference problematic.

First, from a physiological point of view, it has been demonstrated that human brain functioning is unlikely to be impaired by the negligible amount of glucose consumed during self-control tasks (Kurzban, 2010; see also Beedie & Lane, 2012). In the meantime, these doubts have been reinforced by an increasing body of evidence suggesting that merely rinsing one's mouth with glucose solution is sufficient to counteract ego depletion (Hagger & Chatzisarantis, 2012; Molden et al., 2012; Sanders, Shirk, Burgin, & Martin, 2012; but see Carter & McCullough, 2013a). A further line of research suggests that the observation of glucose effects on ego depletion depends on the subjects' implicit beliefs about willpower limitations (Job, Walton, Bernecker, & Dweck, 2013). Second, from a statistical perspective, the original results supporting a role for blood glucose in self-control (Gailliot et al., 2007) are highly implausible (Schimmack, 2012). In total, Gailliot et al. (2007) reported significant results for nine studies involving predominantly small sample sizes. Across these studies, effect sizes were strongly negatively correlated

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with sample sizes and total power (i.e., the probability to obtain only significant results) was less than 1% (Schimmack, 2012). Hence, in all probability, the effect sizes reported by Gailliot et al. (2007) are inflated, potentially as a result of selective reporting of significant results. Third, re-analyses (Kurzban, 2010; Schimmack, 2012) and replications (Lange & Eggert, 2014) of studies supporting the role of glucose in self-control have generated sobering results. When using more powerful designs than applied in the original studies, neither the correlation between blood glucose levels and task performance on a second self-control task in ego-depleted individuals (Dvorak & Simons, 2009; reanalyzed by Schimmack, 2012) nor the counteracting effect of glucose administration (Lange & Eggert, 2014) could be replicated.

In view of these reasonable challenges of the glucose model of self-control, further replication studies are crucial to determine the reliability of the original findings (Frank & Saxe, 2012; Schimmack, 2012; Simmons, Nelson, & Simonsohn, 2011). In their aforementioned replication attempt, Lange and Eggert (2014) could demonstrate that participants' tendency to discount delayed rewards was unaffected by the experimental administration of sugar-containing drinks between self-control tasks. In line with the design applied by Wang & Dvorak (2010), but in contrast to most other studies investigating the effect of ego depletion (Hagger et al., 2010), they used the same laboratory task (i.e., delay discounting) as both depletion task and dependent measure.

Recently, Dewitte, Bruyneel, and Geyskens (2009) reported performances on a second self-control task to be impaired only after performing a different task. As a consequence, it remains possible that the experiment reported in Lange and Eggert (2014) failed to induce ego depletion and that the exhaustion of self-control resources can be moderated by sugar consumption only when dissimilar tasks are used. While such a dependence of glucose effects on task dissimilarity would contradict the strength model of self-control, it could still provide valuable insights into the role of blood sugar within alternative frameworks (Dewitte et al., 2009; Inzlicht & Schmeichel, 2012).

Study Overview

Hence, in order to examine the generalizability of the results described above (Lange & Eggert, 2014), we tested the same experimental groups in a second dual-task paradigm involving dissimilar self-control tasks. It is important to note that the experiment reported here cannot be considered a further, independent replication of the original studies conducted by Gailliot and colleagues (Gailliot et al., 2007), as the sample was identical to the one drawn in the context of a previous replication attempt (Lange & Eggert, 2014). However, testing the same participants again in a different dual-task paradigm allowed us to evaluate whether the absence of a significant effect reported by Lange and Eggert (2014) can be attributed to the fact that identical self-control tasks were used before and after the experimental manipulation. If participants who consumed a sugar-containing drink after an initial self-control task performed better on a second, unrelated self-control task than participants who drank an artificially sweetened soda, the counteracting effect of sugar administration on ego depletion would appear to depend on task dissimilarity. In contrast, if the two groups did not differ in performance on the second self-control task, ego depletion (or ego-depletion-like effects) could be concluded to be unaffected by sugar intake, even when self-control is required in different contexts before and after the experimental manipulation.

Method

Participants

A total of 70 undergraduate students (62 female) participated for course credit, which was not contingent on performance. Additional incentives were provided for the five best averaged performances on experimental tasks (20 € each). Participants' age ranged from 18 to 32 years (M = 21.80 years, SD = 2.58 years). Participants were instructed not to eat for 1.5 hours prior to their arrival at the laboratory. Before beginning with the experiment reported here, participants completed a number of behavioral tasks and psychometric questionnaires for about one hour (Lange & Eggert, 2014).

Experimental Tasks

Experimental tasks were presented on a 24 inch flat screen (Samsung, Seoul, South Korea). A classic go/no-go paradigm (GNG, see for instance Eigsti et al., 2006) was designed using OpenSesame 0.24 (Mathôt, Schreij, & Theeuwes, 2012) and utilized as the depletion task. Participants were required to respond (press the space bar) as fast as possible whenever a frequent go stimulus (red circle, frequency: 80%) appeared in the center of the computer screen, but to withhold responses to infrequent no-go stimuli (green circle, frequency: 20%) for 1500 ms. Establishing a presentation ratio (go vs. no-go) of 4: 1 and an "unnatural" stimulus-response mapping (red = go; green = no-go) forced participants to inhibit predominant go responses when confronted with a infrequent no-go stimulus. During 75 initial training trials, participants instrumentally learned about task contingencies via visual and auditory feedback. During 450 subsequent test trials, only negative auditory feedback was provided after misses (not responding to a go stimulus within 1500 ms) and false alarms (responding to a no-go stimulus). In order to increase the demand for inhibitory control, four task-irrelevant distractors (circles randomly varying in color) were configured around the central target stimulus. Between trials, a fixation cross was presented for 600 ms (inter-trial interval, ITI) in the center of the display. The number of false alarms committed during the test trials was used as an inverted measure of participants' self-control prior to the experimental manipulation.

The popular computer game Tetris (Pajitnov, 1985) was introduced as a novel experimental task to measure self-control. Tetris requires the player to move and rotate tetrominoes, pieces consisting of four squares that are connected orthogonally, in order to compose horizontal lines of ten square blocks. As soon as a line is completed, the blocks disappear and a defined number of points is added to the player's score. Interestingly, the idea behind the game's scoring formula reflects the contingencies involved in delay-discounting paradigms. Players can either complete single lines associated with no delay and a small amount of points, or attempt to clear multiple lines at once which involves a larger delay of reward and a higher risk of failing, but also a possible reward which is larger than the number of points obtained by a correspondent number of single line clears. Further, it was shown that playing Tetris consumed a considerable amount of glucose (Haier, Siegel, Tang, Abel, & Buchsbaum, 1992), suggesting that this task draws from a postulated common self-control resource as well (Gailliot & Baumeister, 2007). In the present study, each participant played the freeware version Tetris Unlimited 0.5.0[1] for ten minutes, starting from level one. Participants were instructed to score as many points as possible. When the stack of pieces reached the top of the playing field before time ran out (causing the current game to end), participants had to start again from level one until a total playing time of ten minutes was reached.

In order to obtain a dependent measure of self-control, we opted to divide the number of single line clears by the total number of lines completed by a participant, yielding the proportion of single lines as an operationalization of shortsighted and, hence, not self-controlled behavior. Alternative measures (proportion of four-line clears, total score, total number of lines, number of restarts) are reported as well to avoid the possibility that our results are due to the more or less arbitrary choice of the dependent variable.

Procedure and Design

Prior to arrival at the laboratory, participants were randomly assigned to one of two conditions (experimental group: 30 females, 5 males; control group: 32 females, 3 males). After entering the laboratory, they completed informed consent forms before their initial blood glucose level (T_1) was assessed (Contour® XT meter, Bayer AG, Leverkusen, Germany). Subsequently, they were tested according to the procedure described by Lange and Eggert (2014) before completing the GNG task. Depending on condition, participants then consumed 250 ml of caffeine-free soda, which contained either sugar (7 Up®; experimental condition) or an artificial sweetener (7 Up light®; control condition) while being blind to group allocation. After consumption, they rated the pleasantness of the soda as well as their current state of hunger and exhaustion on an 11-point Likert scale. In order to allow the sugar from the drink to be metabolized (Gailliot et al., 2007) participants then completed questionnaires (demographic information, personality scales) for an interval of 10 to 15 minutes. Following the second assessment of blood glucose (T_2), participants completed the second self-control task within this dual-task paradigm by playing Tetris for 10 minutes. During the experiment, the experimenter was present in the laboratory but separated from the participant by a wall in the middle of the room.

Note that the tasks administered within our experimental procedure did not fulfill any function in the study reported by Lange and Eggert (2014). Specifically, these authors administered a selective attention task as well as two blocks of trials on a delay-discounting task which had to be completed prior to the depletion task of the present study.

Data Analysis

Statistical analyses were performed using SPSS 20.0 (IBM, Armonk, NY). The level of significance was set at $\alpha = .05$. Statistical power of the group comparisons performed during data analysis was estimated using G*Power 3.1.5 (Faul, Erdfelder, Lang, & Buchner, 2007). Based on the meta-analysis by Hagger et al. (2010) we set the expected effect size to $d = 0.75$.

Investigating whether ego depletion is counteracted by sugar administration required the comparison of self-control performances between depleted individuals who either received a sugar-containing drink (experimental condition) or an artificially sweetened placebo (control condition). This analysis involved contrasting Tetris performances (proportions of simple lines, proportion of four-line clears, total score, total number of lines, number of restarts) across conditions by one-tailed t-tests. As revealed by **Table 1**, sugar and placebo group appeared to differ in their experience with the video game Tetris. Analyses of covariance (ANCOVA) were performed to evaluate the effects of soda supplementation on Tetris performance when a priori group differences in Tetris experience were controlled. As a manipulation check, blood glucose levels were compared between groups and time points (before and after sugar administration) using t-tests.

Results

Sugar and placebo group did not differ with respect to their initial blood glucose level, $t(68) = 0.18$, $p = .86$, $d = 0.04$ (see **Table 1**). However, blood glucose levels at T_2 were significantly higher in individuals having consumed a sugar-containing drink as compared to participants who received a sweet placebo, $t(68) = 8.07$, $p < .001$, $d = 1.93$, indicating that the experimental manipulation was successful. Paralleling the results of Wang and Dvorak (2010), blood glucose was both increased in the sugar group, $t(34) = 10.04$, $p < .001$, $d = 3.44$, and decreased in control participants, $t(34) = 4.74$, $p < .001$, $d = 1.63$ (see **Figure 1**).

Regarding the main analysis of our study, the proportion of simple lines completed during 10 minutes of playing Tetris did not differ as a function of group assignment, $t(68) = 0.05$, $p = .96$, $d = -0.01$, even when controlled for Tetris experience, $F(1, 67) = 1.66$, $p = .20$, $\eta_p^2 = .02$. Repeating the ANCOVA with the proportion of four-line clears, $F(1, 67) = 0.32$, $p = .57$, $\eta_p^2 = .01$, participants' total score on the Tetris task, $F(1, 66) = 0.56$, $p = .46$, $\eta_p^2 = .01$, the total number of lines, $F(1, 66) = 1.28$, $p = .26$, $\eta_p^2 = .02$, or the number of restarts, $F(1, 66) = 0.11$, $p = .74$, $\eta_p^2 = .00$, as alternative outcomes yielded similar results. Intercorrelations between the Tetris measures obtained in our study are provided in **Table 2**. Group comparisons yielded a statistical power of .93 ($N = 70$, $\alpha = .05$, $d = 0.75$).

	sugar group		placebo group		
Measure	***M***	***SD***	***M***	***SD***	***d***
Personal Characteristics					
Age (years)	21.80	2.22	21.79	2.94	0.00
BMI (kg/m^2)	21.79	3.08	21.46	2.61	0.11
Tetris experience	2.06	0.87	2.66	1.03	-0.63*
State variables					
Blood glucose (mg/dl) T_1	99.74	33.91	98.63	16.52	0.04
Blood glucose (mg/dl) T_2	130.11	30.55	86.40	9.67	1.93*
Pleasantness	6.31	1.80	5.80	2.59	0.23
Hunger	3.86	2.50	4.57	2.81	-0.27
Exhaustion	5.51	2.02	5.14	1.91	0.19
Behavioral tasks					
GNG_false alarms	6.51	4.70	8.57	6.67	-0.36
Tetris_% of single-line clears	54.41	16.73	54.65	20.17	-0.01
Tetris_% of four-line clears	6.53	12.00	5.91	11.48	0.05
Tetris_total score	6866.76	4355.84	7665.20	4882.22	-0.17
Tetris_total number of lines	35.57	16.01	35.77	16.69	-0.13
Tetris_number of restarts	0.63	0.65	0.66	0.59	-0.05

Note. GNG = go/no-go task, *d* = standardized mean difference experimental group - control group. $^*p < .05$.

Table 1: Group means, SDs and differences on demographic, behavioral and state variables.

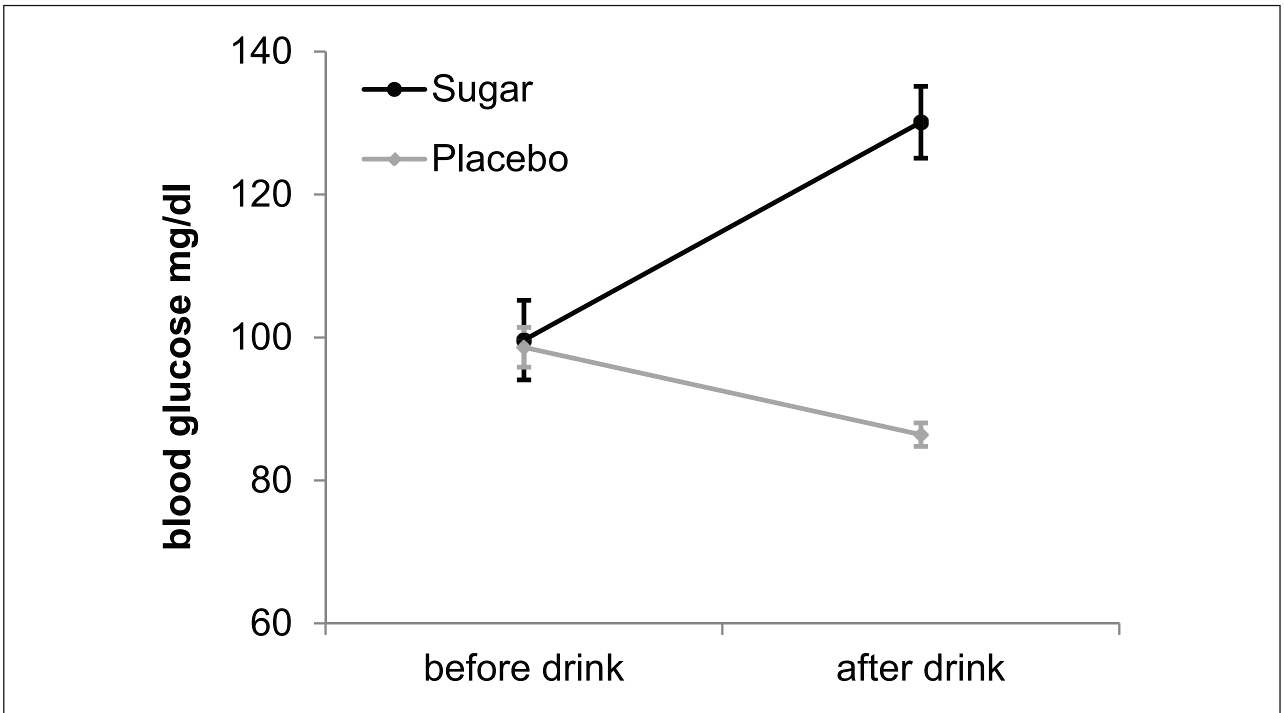

Figure 1: Mean blood glucose levels before and after sugar administration as a function of group assignment. The substantial group difference after drink consumption indicates that the experimental manipulation was successful. Error bars represent standard error of the mean.

	proportion of simple lines	proportion of four-line clears	total score	total number of lines
proportion of four-line clears	-.48**			
total score	-.53**	.35**		
total number of lines	-.53**	.25*	.93**	
number of restarts	.30*	-.02	-.18	-.25*

Note. $^{*}p < .05$, $^{**}p < .01$.

Table 2: Intercorrelations of Tetris outcome variables.

Note that this value is a conservative estimate as it does not take into account the increase in power associated with adjusting for Tetris experience.

Discussion

In line with the experiment reported by Lange and Eggert (2014), we did not find a significant effect of sugar administration on ego depletion. This observation is inconsistent with the results obtained by Gailliot, Baumeister, and colleagues (Gailliot et al., 2007; DeWall et al., 2008; Masicampo & Baumeister, 2008; Gailliot et al., 2009). Statistical power analysis indicated that the dual-task design applied in this study was sufficiently sensitive to detect an effect as large as described by Hagger et. al. (2010). Hence, given the present data, the probability of a Type II error is very low, raising the question of which explanations can account for this divergence of results.

First, performance in the video game Tetris might be considered an inappropriate operationalization of self-control. The choice not to complete a single line but to wait for the delayed possibility to gain a larger amount of points, however, is functionally equivalent to the choice of a delayed reward in a temporal discounting task. Hence, it is reasonable to assume that our dependent measure reflects self-controlled behavior, even when defined as narrowly as “the choice of a larger, more delayed reinforcer over a smaller, less delayed reinforcer” (Logue & King, 1991, p. 105). In addition, previous studies investigating the ego-depletion effect have applied a rather broad definition of a self-control task (i.e., tasks requiring “the effortful suppression of an impulse or overriding of a habitual or dominant response”, Hagger et al., 2010, p. 499) which is arguably met by the Tetris paradigm.

Second, when reasoning within a resource account of self-control, one could attribute the lack of a substantial group difference in our study to a failure of either the depletion task or the experimental manipulation to sufficiently affect the level of a hypothetical self-control resource. Note, however, that participants in the arguably best-controlled study on the effect of sugar administration on ego depletion (Wang & Dvorak, 2010) were only required to complete seven trials of delay discounting during the depletion task. In contrast, participants had to maintain attention to the GNG task for 450 trials in our study. Furthermore, the difference in blood glucose levels between the two experimental groups that served in our experiment (44 mg/dl) was slightly more extreme than the one obtained in the study of Wang and Dvorak (2010; 31 mg/dl). As a consequence, group differences caused by the depletion and differential refilling of a self-control resource should be more pronounced in our study.

Third, participants might have been motivated to achieve high scores while playing Tetris since monetary incentives were offered for the best performances on the total of the experimental tasks. It is possible that this increased motivation has masked the effect of blood glucose manipulation as Muraven and Slessareva (2003) have shown that providing incentives completely erases the ego-depletion effect. Along the same lines, playing Tetris might have induced positive affect which then encouraged participants in both groups to perform well on the task.

Finally, it may well be that, in fact, there is no “large and homogeneous effect” (Hagger et al., 2010, p. 514) of sugar consumption on ego depletion. The studies supporting the idea that self-control relies on glucose as a limited physiological resource could be demonstrated to be statistically incredible (Schimmack, 2012) and methodologically problematic (Kurzban, 2010; Lange & Eggert, 2014). Against this background, the results reported here and elsewhere (Lange & Eggert, 2014) indicate that the effect of sugar on ego depletion has been substantially overestimated. The findings reported by Gailliot and others are most likely due to chance or publication bias and, hence, the glucose model of self-control (Gailliot et al., 2007) lacks empirical justification. Importantly, the present results suggest that the absence of a significant sugar effect in the study by Lange and Eggert (2014) cannot be attributed to the fact that participants were exposed to similar self-control tasks before and after the experimental manipulation. As a corollary, blood glucose can be regarded to play a negligible role not only in resource models of self-control, but also in alternative frameworks accounting for ego-depletion-like effects in dual-task paradigms (Dewitte et al., 2009, Inzlicht & Schmeichel, 2012). Drawing on the conflict model of cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001), Dewitte et al. (2009) have argued that solving the response conflicts in a second self-control task might be impeded when control processes that have been recruited to solve a different response conflict in the first task are still activated. Along similar lines, Inzlicht and Schmeichel (2012) suggested performance deficits on a second self-control task to be caused by the costs associated with task-set switching or attentional disruption. By showing that sugar administration did not improve participants' performance on second self-control task involving a novel response conflict (i.e., the conflict between shortsighted and farsighted Tetris strategies), our study suggests that potential processes of conflict adaption or task-set switching within a dual-task paradigm are not facilitated by glucose.

Alternative accounts of self-control fatigue

Accumulating evidence against the proposal that glucose reflects the limited fuel required to exert self-control also presents a substantial challenge to the strength model of self-control. Without a plausible candidate for the putative resource of self-control energy, the scientific value of the resource metaphor can be questioned (Kurzban, 2010). In view of the theoretical and empirical difficulties of resource accounts (Kurzban, Duckworth, Kable, & Myers, 2013; Navon, 1984), a number of alternative ideas have been proposed to account for ego-depletion-like effects. As mentioned above, Inzlicht and Schmeichel (2012) have suggested the switch of mindsets between dissimilar self-control tasks to be one factor explaining performance decrements on the consecutive task. In addition, their process model of self-control depletion (see also Inzlicht, Schmeichel, & Macrae, 2014) holds that self-control exertion is accompanied by shifts in motivation, attention and emotion. When then confronted with a second self-control task, participants are, for instance, believed to be less motivated to adhere to task-relevant goals (unless they receive incentives to do so; Muraven & Slessareva, 2003). A similar proposal has been presented by Kurzban et al. (2013) who put particular emphasis on the costs and benefits associated with expending effort on a self-control task. Finally, a series of studies by Job, Dweck, and Walton (2010) suggests that self-control might be depletable, but only in those participants who (are led to) believe that willpower relies on a limited resource. While we believe that models along these lines are preferable to a resource account of self-control depletion, we would also like to refer to the possibility that ego depletion might actually not occur and, hence, not require any explanation (Carter & McCullough, 2013b). Scrutinizing the meta-analysis by Hagger et al. (2010), Carter and McCullough suggested that the ego-depletion effect has been substantially overestimated and might be small at most. Hence, clarifying whether the ego-depletion effect needs to be explained at all might be a more important challenge for future research than finding an appropriate theoretical framing for the putative effect.

Conclusion

When combined with other lines of criticism (Kurzban, 2010; Lange & Eggert, 2014; Schimmack, 2012), our results illustrate that there are few and scientifically insufficient reasons to believe in a significant role for sugar in ego depletion. To date, the original study by Gailliot et al. (2007) has been cited over 500 times; their findings were considered for frameworks in diverse fields of the behavioral sciences and inspired numerous experiments like the one presented here. In view of the current state of the evidence, it appears that large parts of this research have been misinformed, highlighting how costly false-positive results can be (Simmons et al., 2011). In order to minimize these costs, independent replication studies and thorough reanalyses are of crucial importance. If the evidence against the glucose model keeps accumulating while attracting more and more attention, it might serve as a valuable case study on how science may be able to correct itself.

Notes

[1] Retrieved from: www.chip.de/downloads/Tetris-Unlimited-0.5.0_13015145.html

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How to cite this article: Lange, F., Seer, C., Rapior, M., Rose, J. and Eggert, F. (2014). Turn It All You Want: Still No Effect of Sugar Consumption on Ego Depletion. *Journal of European Psychology Students, 5*(3), 1-8, DOI: http://dx.doi.org/10.5334/jeps.cc

Published: 24 June 2014

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