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Does ego depletion impair adaptive performance? A longitudinal analysis

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Abstract: Adaptive performance (AP) refers to functional behavioral reactions to changes and it is considered an important performance dimension. In the present study, the influence of ego depletion on AP was examined using an experimental longitudinal design. According to the ego-depletion theory, self-control is a limited resource that can be depleted. Using those resources may lead to performance impairment on subsequent tasks requiring self-control. In the present study, one task was used to induce ego depletion in the experimental group by using a harder version of the task than in the control group. Performance differences on a second task were used to measure the influence of ego depletion on performance. After 80 trials requirements of the second task were changed in order to gauge AP. Perceived ego depletion and cognitive abilities were included as additional performance predictors. Neither objective nor perceived ego depletion was related to AP. In contrast, cognitive abilities promoted transition adaption and reacquisition adaption.

Subjects: Multidisciplinary Psychology; Experimental Design & Research Methods; Quantitative Methods;; Factor Analysis, SEM,Multilevel & Longitudinal Modeling; Intelligence Testing & Assessment; Personality; Work & Organizational Psychology

Keywords: adaptive performance; adaption to change; ego depletion; cognitive abilities; longitudinal; discontinuous growth models

1. Does ego depletion impair adaptive performance? A longitudinal analysis

Adaptive performance (AP) refers to "altering behavior to meet the demands of a new situation, event, or set of circumstances" (Pulakos, Arad, Donovan, & Plamondon, 2000, p. 615). Its importance can be illustrated by the range of jobs and activities requiring such reactions, e.g. emergency landing, complications during a surgery, implementation of new software in the company, new coworkers,

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PUBLIC INTEREST STATEMENT

In our everyday lives, we are often confronted with changes, i.e. new co-workers or new software. Sometimes lives can depend on our reactions to changes (e.g. emergency landing, complications during surgery). Within the context of work and education, good responses to changes can be described as adaptive performance. In the current study, self-control and intelligence are considered as factors that could influence adaptive performance. Due to the fact that adaptation is a process, a longitudinal study was conducted, which enables following performance change over time.

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retirement. At the same time, those examples make it clear that AP is a broad construct. Indeed, Pulakos et al. (2000) proposed eight dimensions of adaptive performance, i.e. handling work stress and dealing with uncertain or unpredictable work situations. Nevertheless, the mentioned succinct definition illustrates that all types of adaptive performance have something in common: dealing successfully with changes. The relevance of adaptive performance has been acknowledged by other researchers so that AP is considered a separate job performance dimension, along task performance, organizational citizenship behavior, counterproductive work behavior, creative and innovative performance (Harari, Reaves, & Viswesvaran, 2016). In the recent years researchers increased their efforts to study AP as evidenced by the extending list of review articles devoted to this research field (Baard, Rench, & Kozlowski, 2014; Bohle Carbonell, Stalmeijer, Könings, Segers, & van Merriënboer, 2014; Jundt, Shoss, & Huang, 2015; Maynard, Kennedy, & Sommer, 2015).

However, finding reliable predictors of adaptive performance turned out to be a difficult task. To illustrate, according to meta-analytic results (Huang, Ryan, Zabel, & Palmer, 2014; Woo, Chernyshenko, Stark, & Conz, 2014) the average relationship between Big Five personality traits and adaptive performance is weak. Hitherto only cognitive abilities could be identified as a good predictor across many cross-sectional studies (M. Carter & Beier, 2010; Kozlowski et al., 2001; Morgan et al., 2013; Stokes, Schneider, & Lyons, 2010). Nevertheless, usually performance is determined not only by abilities but also through self-regulatory aspects, i.e. motivation (Van Yperen, Blaga, & Postmes, 2015). Unfortunately, such variables have not been examined as often as cognitive abilities in the context of adaptive performance (Jundt et al., 2015). The main aim of the present study is to broaden the understanding of the self-regulation's role in the AP context by examining one previously unconsidered self-regulatory variable as predictor of AP.

Hitherto researchers have concentrated on searching for distal self-regulatory predictors of AP, i.e. trait goal orientation. However, the respective findings are mixed. Trait goal orientation seems to be related to subjective adaptive performance ratings (e.g. self-reports) rather than to objective AP scores, i.e. errors (Ahearne, Lam, Mathieu, & Bolander, 2010; Davis, Dibrell, Craig, & Green, 2013; Hardy, Imose, & Day, 2014; LePine, 2005). Therefore, in the present study the influence of a more proximal self-regulatory predictor of performance—ego depletion—was examined experimentally. Ego depletion involves processes like monitoring and attention (Inzlicht & Schmeichel, 2012), which lie at the core of self-regulation (Sitzmann & Ely, 2011). According to ego-depletion theory, increased use of such self-regulatory resources results in performance impairment on tasks involving self-control. This pattern of results was replicated in many studies conducted within the first 10 years after the first study was published (Hagger, Wood, Stiff, & Chatzisarantis, 2010). However, according to recent systematic reviews of the literature the findings are mixed (E. C. Carter & McCullough, 2014; Hagger et al., 2016). Furthermore, ego depletion has not been examined across certain forms of performance, i.e. AP. The current study was conducted in order to remedy this. In the next sections, a short overview of ego-depletion findings is provided. Furthemore, two frameworks are introduced (dual-task paradigm and task-change paradigm), which will be used in the present study to examine the relationship between ego depletion and AP.

1.1. Ego depletion and dual-task paradigm

It has been already pointed out that ego depletion is associated with research on self-regulation. Conscious self-regulation is often referred to as self-control (Hagger et al., 2010) and it plays an important role in our everyday lives because people constantly need to resolve conflicts between short-term and long-term motivations (Fujita, 2011). Lack of self-control can result in aggression (Ayduk, Rodriguez, Mischel, Shoda, & Wright, 2007) or procrastination (Ariely & Wertenbroch, 2002). Furthermore, it has long-term effects on academic and social competencies (Mischel, Shoda, & Peake, 1988), and delaying weight gains (Schlam, Wilson, Shoda, Mischel, & Ayduk, 2013). In the last three decades a multitude of studies has been devoted to short-term consequences of self-control failure typically subsumed under an umbrella term of ego depletion (Hagger et al., 2010), a term popularized by Baumeister and colleagues (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Baumeister & Tierney, 2011). The mechanism underlying the ego depletion has been often illustrated by two analogies: resource analogy and muscle analogy (Baumeister,

Gailliot, DeWall, & Oaten, 2006; Evans, Boggero, & Segerstrom, 2015). Following the first analogy self-control can be regarded as a limited resource. Exerting self-control depletes those resources, which means that fewer self-control resources are available for tackling next challenges. In the end, people with depleted resources may not be able to exert self-control anymore. As in the case of tired muscles a break is necessary to restore power or resources.

Often studies devoted to this topic are aligned to the dual-task paradigm (Hagger et al., 2010). In the simplest case, two groups (control group and experimental group) are confronted with two tasks. In the control group, the first task requires no self-control or less self-control than the respective task in the experimental group. In contrast, the second task is the same for both groups and it requires self-control. Thus, according to the ego-depletion theory, if experimental group shows worse performance on the second task than control group then this performance difference can be explained by depletion of the self-control resources caused by the first task. This pattern of results was replicated in many studies as evidenced by the mean effect size of medium magnitude ($d = 0.62$), which was computed by Hagger and colleagues using data from 83 studies. However, researchers using other meta-analytic methods reported somewhat smaller effects (Carter & McCullough, 2014).

In addition to eliciting ego depletion, one can also ask participants to rate the perceived ego depletion. Generally, according to the meta-analytic findings of Hagger et al. (2010), people in the ego-depletion condition tend to report higher levels of perceived ego depletion than people in the control group. Nevertheless, some inconsistency between the actual ego depletion and the subjective or perceived ego depletion has been reported (Govorun & Payne, 2006). Thus, it can be useful to consider both objective and subjective ego depletion when conducting studies.

Ego depletion has been linked to work-related outcomes, e.g. researchers have found a negative relationship between depletion of self-control resources and organizational citizenship behavior (Johnson, Lanaj, & Barnes, 2014). Others have examined the relationship between ego depletion and unethical behavior (Barnes, Schaubroeck, Huth, & Ghumman, 2011; Lin, Ma, & Johnson, 2016). However, nobody has investigated the effects of ego depletion on adaptive performance. The present study is aimed at closing this gap. To put the influence of ego depletion on AP into perspective an already established predictor was also included in the current study—cognitive abilities.

1.2. Adaptive performance and task-change paradigm

There are several possibilities to assess the impact of ego depletion on adaptive performance, because the latter can be gauged in various ways. One can use scales to obtain subjective adaptive performance ratings, e.g. self-reports, supervisors' or peers' ratings (Charbonnier-Voirin & Roussel, 2012; Stokes et al., 2010), but many researchers use objective scores (e.g. accuracy) as indicators of AP.

Usually, objective scores are based on tasks aligned to the task-change paradigm (Lang & Bliese, 2009; Niessen & Jimmieson, 2016): It is particularly attractive because it enables measuring the adaption process (see Figure 1 for a graphic depiction). Participants are asked to work on a task and at some stage, they are confronted with a task-change. In extreme cases, several task characteristics may be changed resulting in a task that can be "more difficult, complex, and dynamic" (Bell & Kozlowski, 2008, p. 302). Peoples' behavioral reactions to the induced change are of interest when one wishes to capture adaptive performance. Thus, one can differentiate between pre-change performance and post-change performance (in Figure 1 measurement occasions 1–5 and 6–10, respectively). For many years adaptive performance was equated with post-change performance. Lang and Bliese (2009) extended this framework and proposed four performance components in the task change-paradigm; basal task performance, skill acquisition, transition adaption, and reacquisition adaption. In contrast to focusing on zero-order correlations between the input and the outcome—i.e. cognitive abilities as input and mean adaptive performance as outcome—this approach enables tracing the performance trajectories over time (Baard et al., 2014).

Basal task performance typically refers to the mean performance at the first measurement occasion and skill acquisition is the learning rate in the pre-change phase. The two other

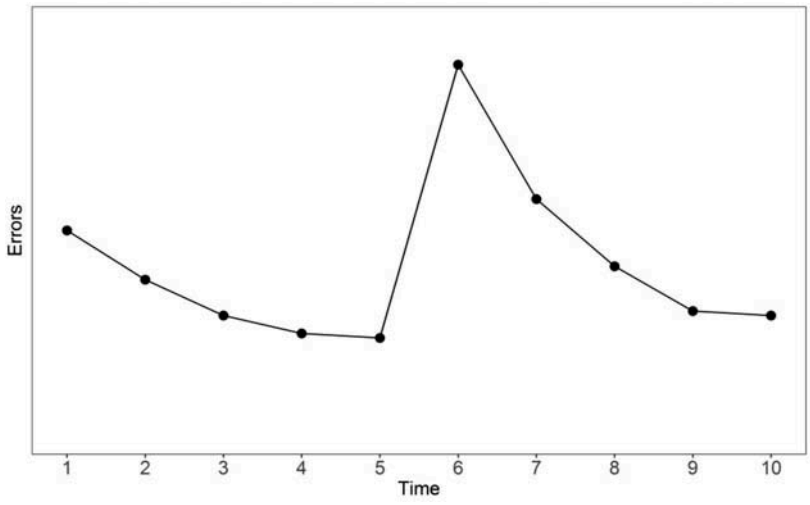

Figure 1. Visualization of task-change paradigm, which is often used to measure adaptive performance. In this case, participants are confronted with change after the fifth measurement occasion as evidenced by the performance impairment (increase in errors). Thus, performance on the measurement occasions 1–5 represents the pre-change phase and measurement occasions 6–10 refer to the post-change phase.

components are helpful when one wants to differentiate between task performance and adaptive performance. Specifically, transition adaption refers to the immediate performance change caused by the new task. Usually one can observe a performance decrease. However, eventually people reach a better and stable level of performance as they are learning the changed task. The last performance component—reacquisition adaption or recovery—is based on the learning rate in the post-change phase. Both transition adaption and reacquisition adaption can be interpreted in absolute terms or relatively to the pre-change phase values, i.e. reacquisition adaption can be defined relatively as the difference between learning rate in the pre-change phase and (re)learning rate in the post-change phase (Bliese & Lang, 2016).

Unfortunately, subjective AP ratings and objective AP scores cannot be used interchangeably as they are often only moderately correlated (Baumgartner, 2015; Upchurch, 2013, but see also Stokes et al., 2010 for a stronger relationship). It is not necessarily the case that one of those measures is generally flawed. Instead, they may tap into different aspects of adaptive performance. Subjective adaptive performance ratings might gauge more AP dimensions than isolated tasks. At the same time, the correlations between subjective AP ratings and predictors are more susceptible to common method bias, because most of the considered AP predictors (i.e. Big Five, goal orientation) are assessed via the same method (questionnaires). Thus, it is possible that the strength of the relationship is overestimated through the use of a common method (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). In the present study, the focus lies on the effects of ego depletion on adaptive performance. AP was assessed using objective scores within the introduced longitudinal framework. This decision was motivated by the fact that the framework can be used to differentiate between the standard (pre-change) performance impairment due to ego depletion and its additional influence on adaptive performance.

1.3. Ego depletion and adaptive performance

As it was already mentioned, there are many benefits of self-control (Bertrams & Dickhäuser, 2009; de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012; Tangney, Baumeister, & Boone, 2004). Some of them can be seen as an exemplification of successful adaption, i.e. good school and work performance, less procrastination, optimal emotional reactions, and fewer problems with psychological disorders. However, negative effects of self-control are also possible as illustrated by the ego-depletion effect. Specifically, repeated exertion of self-control may result in low performance if the subsequent activities also involve self-control (Hagger et al., 2010). Due to the fact that adaption to changes requires self-control, it can also be negatively affected by the ego depletion. To elaborate, in order to show AP people have to detect the change and realize that

strategies utilized before the change aren't so efficient after the change (Howe, 2019; Jundt, 2009). Consequently, they need to identify better strategies and refrain from using the older and potentially inefficient or even harmful strategies. Such inhibition of responses involves self-control (Hagger et al., 2010). Due to the fact that exerting self-control on preceding tasks may deplete self-control resources needed for tackling tasks requiring adaptive performance one could assert that ego depletion impairs AP.

To ensure that the AP task requires self-control in the present study a task was chosen that according to Hagger and colleagues has been often used in the ego-depletion research field. The chosen task (Stroop test) is known to involve inhibition (MacLeod, 1991) so changing a task rule to enable measuring AP would inevitably increase the self-control demands. After all, people need to modify their strategies after the change, i.e. abandon automated strategies and implement new strategies, which requires self-control. Thus, it was expected that people, who experienced ego depletion, would show worse adaptive performance than participants in the control group. In accordance with previous studies (Lang & Bliese, 2009; Niessen & Jimmieson, 2016) it was differentiated between two AP components: transition adaption and reacquisition adaption.

Hypothesis 1a: *Ego depletion impairs transition adaption.*

Hypothesis 1b: *Ego depletion impairs reacquisition adaption*.

1.4. Other performance predictors

In addition to objective ego depletion perceived ego depletion and cognitive abilities were also included as predictors of adaptive performance. Whereas the former pertains to the main research question of the present study (relationship between ego depletion and AP), the latter has been identified as an important AP predictor in the previous studies. Thus, inclusion of cognitive abilities makes it possible to compare the effects of novel predictors with an established predictor.

Subjective ego depletion. Although objective ego depletion is often accompanied by elevated subjective fatigue or difficulty (Hagger et al., 2010) there is also evidence that such perceived depletion can influence performance independently (Clarkson, Hirt, Jia, & Alexander, 2010). Thus, both an objective and a subjective ego-depletion measure were included in the current study. As in the case of objective ego depletion, it was expected that perceived ego depletion would impair adaptive performance.

Hypothesis 2a: *Perceived ego depletion impairs transition adaption.*

Hypothesis 2b: *Perceived ego depletion impairs reacquisition adaption*.

1.4.1. Cognitive abilities

The relationship between cognitive abilities and adaptive performance was explored on numerous occasions (i.e. Bell & Kozlowski, 2002; Frank & Kluge, 2017; Keith, Richter, & Naumann, 2010; Lang & Bliese, 2009). Usually, cognitive abilities seem to promote AP. After all, abilities such as processing speed, short-term memory and reasoning may help detect changes and find optimal strategies in novel situations.

However, negative effects of cognitive abilities on adaptive performance have also been reported. Specifically, Lang and Bliese (2009) have found that people with high general mental abilities show on average a larger performance drop immediately after the change than people with lower abilities. One may be inclined to view this finding as something that corroborates the "less is more" hypothesis, the notion that relatively low cognitive abilities may lead to better performance than higher abilities. However, the less is more approach in general and the interpretation of Lang and Bliese's findings within this framework have been criticized (Beier & Oswald, 2012). Furthermore, the authors distanced themselves from this claim when they pointed out that

even though highly intelligent people had a bigger performance drop after the change they still performed better than people with relatively low cognitive abilities (Lang & Bliese, 2012). Moreover, two other researchers couldn't replicate the original finding that cognitive abilities are negatively related to adaptive performance. In one dissertation (Wheeler, 2012) the findings were mixed and in another study a positive rather than negative relationship between intelligence and AP was found (Howe, 2019). Moreover, the vast majority of cross-sectional findings (zero-order correlations) in the extant literature has been positive, including the work of Lang and Bliese (i.e. Bell & Kozlowski, 2002; Frank & Kluge, 2017; Keith et al., 2010; Lang & Bliese, 2009). Negative effects are mostly of very small magnitude and statistically insignificant (i.e. Blickle et al., 2011; Chan & Schmitt, 2002). To illustrate, in a recent meta-analysis only 11 of 119 effect sizes had a negative sign (Stasielowicz, 2019). Based on those findings it was hypothesized that:

Hypothesis 3a: *High cognitive abilities promote transition adaption.*

Hypothesis 3b: *High cognitive abilities promote reacquisition adaption*.

2. Methods

2.1. Sample characteristics and procedure

2.1.1. Participants

The study was conducted in Germany at Osnabrück University and the respective sample consisted primarily of students. The data were collected in the fall of 2015. One hundred and forty-six people took part in the experiment, but data from some participants could not be used in the analyses because some people didn't follow the instructions on the tasks (i.e. ignored the rules). The final sample included data from 139 participants (115 women and 24 men), which were between 18 and 56 years old (M = 21.41, SD = 4.36). The ego-depletion group consisted of 68 people and 71 individuals were in the control group. Furthermore, a third of the sample (40 of 137 people for whom the data were available) had previously encountered the main task used in this study, namely the Stroop task, in some form, i.e. lectures, games, other experiments. Participants could choose between course credit and 10 € as a form of compensation. The participation was voluntary and all participants signed a written consent form.

Tasks. In accordance with the dual-task paradigm which has been often used in the ego-depletion context participants were asked to complete two tasks. Every person was randomly assigned to one of the two conditions (ego depletion or control group). The only difference between the conditions pertained to the first task. To induce ego depletion a crossing-outletters task was used (Baumeister et al., 1998; Hagger et al., 2010). Participants in both conditions had to cross out instances of the letter *e* (both lower and upper case) in a statistics text, which was one page long. However, while the control group could cross out all instances of *e* the ego-depletion group had to follow an inhibition rule. Specifically, the participants could only cross out the letter *e* if there were no vowels in the proximity (up to two letters to the left and right within the word). To illustrate, the letter *e* in the word *cluster* could be crossed out, because the other vowel (*u*) was the third letter to the left of *e*, which didn't count as proximity. In contrast, the word *hierarchy* contains two vowels near *e* (*i* and *a*). Thus, participants in the ego-depletion group had to exert self-control and follow the inhibition rule by not crossing out the letter *e*. Participants, who didn't follow the instructions (e.g. ignored the rules when crossing-out the letters) were excluded from data analysis.

In order to gauge the ego-depletion effect a modified Stroop test was chosen (MacLeod, 1991, 1992; Stroop, 1935), because it requires conflict evaluation and resolution (Chuderski & Smolen, 2016) forcing participants to exert self-control. Specifically, color names were presented to participants in different font colors on a computer screen. The four names and font colors (blue, green, yellow, red) were either congruent (e.g. word GREEN in green font color) or incongruent (i.e. word GREEN in yellow font color) and participants were required to indicate the font color by pressing

the respective button on a colored keyboard. However, to increase the task complexity an exception rule was introduced after the practice session has been completed. If the font color was blue then people had to indicate the name instead. This modification enabled gauging adaptive performance. After completing 80 trials with the exception rule participants were confronted with a change. Specifically, the exception color has been changed to red font. People had to adapt to change using feedback (Answer: right vs wrong), which was displayed on the screen after every trial of the Stroop task. Although participants knew that the exception color will change, they didn't know when this event will take place and which color will be the new exception color. In total, every participant completed 176 trials: 16 trials in the practice session (four words in four different font colors), 80 trials in the pre-change phase, and 80 trials in the post-change phase. Thus, the 16 different stimuli were displayed ten times in the test session.

2.1.2. Procedure

To avoid the possibility that answering many questions and completing tasks used to assess cognitive abilities influenced the Stroop task performance participants had to visit the lab two times. Participants were told that different types of tasks should be compared within the study. Duration of both lab visits varied between participants and it took between 35 and 60 min to complete each part. With the exception of the crossing-out letters task all questionnaires and tasks were presented on a computer screen. During the first part demographic variables, trait self-control, subjective adaptive performance ratings, goal orientation, self-efficacy, fatigue, irritation, and regulatory focus were assessed using questionnaires. Additionally, participants completed an intelligence test in order to assess cognitive abilities.

One week later participants were asked about their mood, dysfunctional perfectionism, need for cognition, optimism, and pessimism. Subsequently, participants completed the task used to induce ego depletion (crossing-out-letters) and were asked about the perceived ego depletion and their mood. Next, they completed the modified Stroop test, which took approximately 15 min. Shortly thereafter they were asked again about the perceived ego depletion and their mood. Next, people were required to provide information whether they had previously encountered a Stroop task in any form (games, lectures, etc.). Finally, three Ishihara tables were used to rule out the possibility that bad performance on the Stroop task was due to color blindness. After the completion of both parts of the experiment, the participants were thanked and received vouchers for the preferred compensation (course credit or 10 €). If desired they also got additional information about the study and left the lab.

2.2. Measures

Many variables were included in the current study but only few of them were of primary interest. Several of the variables named in the procedure section were included for exploratory reasons (i.e. regulatory focus). In the following sections, only variables that were specified in the hypotheses are described. However, in the appendix zero-order correlations between several performance indicators, demographic variables and postulated performance predictors are reported (Table 1). Furthermore, interested readers will find a full correlation matrix in supplementary materials, which includes intercorrelations among 45 variables.

2.2.1. Subjective ego depletion

Similarly to previous studies (Govorun & Payne, 2006; Hagger et al., 2010), subjective ego depletion was assessed using several questions. Specifically, participants were asked after both the crossing-out-letters task and the Stroop test, whether the task was exhausting, effortful, difficult, frustrating, and discouraging. To illustrate, people could indicate on a 9-point scale whether the respective task was, for instance, exhausting (1 = not at all, 9 = very). The scale, which consisted of five items, had good reliability in the present sample, as evidenced by McDonald's omega (Dunn, Baguley, & Brunsden, 2014; Trizano-Hermosilla & Alvarado, 2016) both after the crossing-out-letters task (ω_t = .86) and the modified Stroop task (ω_t = .90). The reliability was computed using the R package *psych*.

Table 1. Zero-order correlations between the assessed variables. Reliability coefficients (McDonald's omega = ω_t) are reported in the diagonal

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Pre-change performance(errors)	-													
2 Post-change performance(errors)	.33	-												
3 Pre-change performance(interference)	.07	−.09	-											
4 Post-change performance(interference)	−.03	−.02	.18	-										
5 Pre-change performance (reaction times)	.02	−.05	.63	.00	-									
6 Post-change performance (reaction times)	.01	.01	.03	.56	.52	-								
7 Experimental condition	−.09	.06	−.05	.10	−.02	.09	-							
8 Stroop task experience	−.09	.00	.10	−.14	.23	.10	−.05	-						
9 Age	.14	.05	.02	.05	.29	.34	.12	.14	-					
10 Sex	−.13	.03	−.01	−.03	.05	.04	.03	.08	.27	-				
11 Final grade(secondary education)	.07	.10	−.12	−.05	.01	.05	.09	.04	.36	.26	-			
12 Perceived ego-depletion T1	.09	−.03	−.02	.00	.05	.08	−.24	.06	−.12	−.10	−.08	(.86)		
13 Perceived ego-depletion T2	.19	.25	−.06	.04	−.05	.03	−.01	−.11	−.05	−.06	.00	.41	(.90)	
14 Cognitive abilities	−.12	−.25	.18	.10	.00	−.09	.00	−.10	−.03	.14	−.08	.05	.08	(.92)

Notes. N= 139, except for Stroop task experience and perceived ego-depletion T2 (n= 137); All correlations $|r| \geq .18$ were statistically significant ($p < .05$, two-tailed). When both variables were continuous Spearman correlations were calculated, when one of the variables was dichotomous point-biserial correlations were computed (equivalent to Pearson's rho), and when both variables were dichotomous (experimental condition, Stroop task experience, sex) phi coefficients were calculated. In order to improve readability not all exploratory correlations are reported here. Interested readers will find a full correlation matrix (csv file) in supplementary materials, however. For a full list of assessed variables (i.e. self-reported social AP) see procedure section; Variables 1–6 are performance indicators (1–2 sum values, 3–6 mean values), smaller values are better; Experimental condition = Ego-depletion group vs control group, the ego-depletion group is the reference category; Stroop task experience = yes vs no; Sex = women vs men; Final grade = German Abitur, smaller values are better; Perceived ego depletion = Subjective ego depletion after the first task (T1, crossing-out-letters) and after the second task (T2, modified Stroop task); Cognitive abilities = Reasoning part of the Wilde-Intelligence-Test (Kersting, Althoff, & Jäger, 2008).

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2.2.2. Cognitive abilities

The reasoning part of Wilde-Intelligence-Test (Kersting et al., 2008) was used to assess cognitive abilities in the present study. It consists of three subtests (analogies, number sequences, and folding), 20 items each. Number of total correct responses was used as the reasoning indicator in the present study (ω_t = .92).

2.2.3. Stroop task performance

Performance on the Stroop task was used to gauge the impact of ego depletion on adaptive performance. Only performance on the trials requiring the use of the exception rule was analyzed, because it was the exception rule that has been changed in the current study. In total, 30 such trials were available: 15 trials in the pre-change phase and 15 trials in the post-change phase. There were three different words written in the exception font color and they were displayed five times in each phase. Specifically, words GREEN, RED, and YELLOW were displayed in blue font in the pre-change phase and words GREEN, BLUE, and YELLOW were displayed in red font in the post-change phase. Each triple was combined, which yielded 10 measurement occasions enabling a longitudinal modeling of performance (compare Figure 1). For each stimulus both the errors and reaction times were recorded as they can be regarded as objective AP scores. Thus, the sum of errors made by each participant and their mean reaction time on each measurement occasion were calculated. However, hitherto AP researchers have concentrated on accuracy as performance indicator (Bell & Kozlowski, 2008; LePine, Colquitt, & Erez, 2000). Thus, to ensure comparability between the studies (i.e. the effect of cognitive abilities on AP: Howe, 2019; Lang & Bliese, 2009; Wheeler, 2012), the focus lies on errors when testing the hypotheses. Nevertheless, explorative analyses using reaction times were also conducted and interested readers will find a respective description in the supplementary materials. Irrespective of the score chosen, high outcome values (errors, reaction times) imply low performance in the present study.

2.3. Statistical analyses

In order to model adaptive performance longitudinally and test the hypotheses discontinuous mixed-effects growth models were utilized in the current study. They have been used on several occasions within the task-change paradigm, which was described in the introductory sections (Howe, 2019; Lang & Bliese, 2009; Niessen & Jimmieson, 2016; Wheeler, 2012). Such models enable one to examine the adaption process and to account for differences in performance trajectories between people. Discontinuity refers to the sudden change in performance trajectory usually observed in the context of adaptive performance. Specifically, sudden performance impairment can be seen after the change. In contrast to standard techniques like ordinary least squares regression models or ANOVA, mixed-effects models enable one to account for differences between people by including not only fixed effects but also random effects (Bliese & Ployhart, 2002; Chan & Schmitt, 2000; Curran, Obeidat, & Losardo, 2010; Ployhart & Vandenberg, 2010; Ployhart & Ward, 2011; Raudenbush, 2001), which may improve models considerably. To illustrate, in the present study participants could make different numbers of errors on the Stroop task at the first measurement occasion (between 0 and 3 errors), which can be modeled by including a random effect for the intercept (r_{0i}). Similarly, it is possible that the performance improvement rate (= skill acquisition, SA) in the pre-change phase is not equal across participants. Instead, the performance change between two consecutive time points could differ between individuals. Also the difference between the actual performance directly after the change and the expected performance (= transition adaption, TA) could vary. Finally, the difference between performance improvement rates in the pre-change phase and the post-change phase (= reacquisition adaption, RA) may also be different across participants. Performance trajectory is not necessarily best described by a straight line (see Figure 1) so it is sometimes advisable to include quadratic effects for learning rates (i.e. skill acquisition), which account for curvilinear patterns in performance trajectories. The coding of the change variables (skill acquisition, transition adaption, etc.) is summarized in Table 2. Furthermore, the following paragraphs contain information about the interpretation of the respective coefficients.

Table 2. Coding of change variables in the current study (discontinuous mixed-effects growth models). See text for explanations

	Measurement occasion									
	Pre-change phase					Post-change phase				
Change Variable	1	2	3	4	5	6	7	8	9	10
SA (Skill acquisition)	0	1	2	3	4	5	6	7	8	9
TA (Transition adaption)	0	0	0	0	0	1	1	1	1	1
RA (Reacquisition adaption)	0	0	0	0	0	0	1	2	3	4
SA^2 (quadratic SA)	0	1	4	9	16	16	16	16	16	16
RA^2 (quadratic RA)	0	0	0	0	0	0	1	4	9	16

Coding of the time variable (here SA) determines how one has to interpret the coefficients, i.e. the intercept (Biesanz, Deeb-Sossa, Papadakis, Bollen, & Curran, 2004). Similarly to previous studies (Lang & Bliese, 2009; Niessen & Jimmieson, 2016), the time variable was scaled so that the value of zero corresponds to the first measurement occasion, the value of one corresponds to the second measurement, etc. It enables one to interpret the intercept as the mean performance on the first measurement occasion. Skill acquisition coefficient indicates the rate of performance change (slope). In this study, a negative SA coefficient implies that people's performance improves over time. In other words: they make fewer errors. If one were to compute mean performance on measurement occasion three, then one would have to multiply the SA coefficient by two and add it to the starting point (intercept, but see also notes under Table 3–5). Other change parameters can be ignored in this calculation, because they have a value of 0 on the third measurement occasion (see Table 2). Furthermore, it is important to note that the adaptive performance coefficients (TA, RA, and RA^2) have to be interpreted relatively to the pre-change phase in the present study. Thus, transition adaption indicates the difference between the expected performance and the actual performance. The expected performance is based on the pre-change phase. In this study a positive sign of the TA coefficient would mean that participants made more errors directly after the change that one would expect based on the intercept and performance improvement rate in the pre-change phase. As to the reacquisition adaption coefficient, it represents the difference in learning rates between the pre-change phase (skill acquisition) and the postchange phase. To illustrate, if both SA and RA coefficients were negative in the current study, then it would imply that people made on average larger improvements in the post-change phase. In other words: the decrease in errors would be more dramatic in the post-change than in the pre-change phase. If SA were negative and RA were equal to zero, then it would mean that the learning rates before the change and after the change were the same and that people in both phases tended to make fewer errors as the task progressed. Other interpretations of TA and RA (i.e. absolute interpretation) are also possible but require the use of other coding schemes (Bliese, Adler, & Flynn, 2017; Bliese & Lang, 2016).

Growth models can be regarded as a special case of multilevel models. Specifically, the ten measurement occasions were nested within individuals in the study. In the current study, the performance trajectory (within-person differences) could be modeled with the change variables (SA, TA, etc.), which represent level 1 parameters. Static predictors (i.e. cognitive abilities) could be used to explain differences between the people and therefore could be regarded as level 2 parameters. Metric level 2 predictors were centered before entering them into the models to ensure that a meaningful interpretation of the coefficients was possible. Final level 1 and 2 equations are presented in the results section and an exemplary model diagram is depicted in Figure 2.

With regard to the interpretation of the coefficients involving level 2 predictors itbuilds on the mentioned change parameters. Intercept refers in such models to the average performance of people with value of 0 in the level 2 predictor. Due to centering of metric variables a value of 0

Table 3. Discontinuous generalized mixed-effects growth models (zero-inflated Poisson model with log link function) predicting change in performance (errors) as a function of experimental condition (ego depletion vs control group)

Variable		Model A			Model B	
	b	*SE*	*z*	*b*	*SE*	*z*
Fixed effects						
Intercept	−1.02	0.12	−8.72*	−0.89	0.16	−5.66*
Skill acquisition (SA)	−0.07	0.04	−1.59	−0.08	0.06	−1.26
Transition adaption (TA)	1.43	0.17	8.58*	1.31	0.23	5.75*
Reacquisition adaption (RA)	−0.39	0.07	−5.45*	−0.42	0.10	−4.33*
Experimental condition				−0.26	0.23	−1.12
SA x Experimental condition				0.01	0.09	0.13
TA x Experimental condition				0.23	0.33	0.68
RA x Experimental condition				0.05	0.13	0.40
Random effects	Variance	*SD*				
Intercept	0.30	0.55		0.30	0.55	
Skill acquisition (SA)	$4.07*10^{-6}$	$2.02*10^{-3}$		$1.20*10^{-7}$	$3.47*10^{-4}$	
Reacquisition adaption (RA)	0.09	0.30		0.09	0.30	
AIC	2446			2449.8		
Log-likelihood	−1214.99			−1212.9		

Notes. *N* = 139; Experimental condition = Ego-depletion group vs control group, ego-depletion group is the reference category; *b*= Regression coefficients are based on predictors, which were orthogonalized within the statistical package, supplementary materials contain a table with regression coefficients that can be used to calculate predicted performance on the raw scale.

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Table 4. Discontinuous generalized mixed-effects growth models (zero-inflated Poisson model with log link function) predicting change in performance (errors) as a function of perceived ego depletion

Variable		Model A			Model C	
	b	*SE*	*z*	*b*	*SE*	*z*
Fixed effects						
Intercept	−1.02	0.12	−8.72*	−1.05	0.12	−8.83*
Skill acquisition (SA)	−0.07	0.04	−1.59	−0.06	0.05	−1.36
Transition adaption (TA)	1.43	0.17	8.58*	1.42	0.17	8.45*
Reacquisition adaption (RA)	−0.39	0.07	−5.45*	−0.40	0.07	−5.49*
Perceived ego depletion				0.21	0.08	2.51*
SA x Perceived ego depletion				−0.03	0.03	−1.07
TA x Perceived ego depletion				−0.06	0.12	−0.53
RA x Perceived ego depletion				−0.01	0.05	0.21
Random effects	Variance	*SD*				
Intercept	0.30	0.55		0.30	0.54	
Skill acquisition (SA)	$4.07*10^{-6}$	$2.02*10^{-3}$		$3.28*10^{-7}$	$5.72*10^{-4}$	
Reacquisition adaption (RA)	0.09	0.30		0.08	0.29	
AIC	2446			2442.1		
Log-likelihood	−1214.99			−1209.03		

Notes. *N*= 139; *b*= Regression coefficients are based on predictors, which were orthogonalized within the statistical package, supplementary materials contain a table with regression coefficients that can be used to calculate predicted performance on the raw scale.

Table 5. Discontinuous generalized mixed-effects growth models (zero-inflated Poisson model with log link function) predicting change in performance (errors) as a function of cognitive abilities

Variable		Model A			Model D	
	b	*SE*	*z*	*b*	*SE*	*z*
Fixed effects						
Intercept	−1.02	0.12	−8.72*	−1.06	0.12	−8.86*
Skill acquisition (SA)	−0.07	0.04	−1.59	−0.05	0.05	−1.14
Transition adaption (TA)	1.43	0.17	8.58*	1.37	0.17	8.21*
Reacquisition adaption (RA)	−0.39	0.07	−5.45*	−0.41	0.07	−5.68*
Cognitive abilities				−0.04	0.01	−3.43*
SA x Cognitive abilities				0.01	$4.30*10^{-3}$	2.82*
TA x Cognitive abilities				−0.04	0.02	−2.65*
RA x Cognitive abilities				−0.02	0.01	−2.54*
Random effects	Variance	*SD*				
Intercept	0.30	0.55		0.26	0.51	
Skill acquisition (SA)	$4.07*10^{-6}$	$2.02*10^{-3}$		$9.50*10^{-7}$	$9.75*10^{-4}$	
Reacquisition adaption (RA)	0.09	0.30		0.09	0.29	
AIC	2446			2434.5		
Log-likelihood	−1214.99			−1205.27		

Notes. *N*= 139; Cognitive abilities = Reasoning part of the Wilde Intelligence Test (Kersting et al., 2008); *b*= Regression coefficients are based on predictors, which were orthogonalized within the statistical package, supplementary materials contain a table with regression coefficients that can be used to calculate predicted performance on the raw scale.

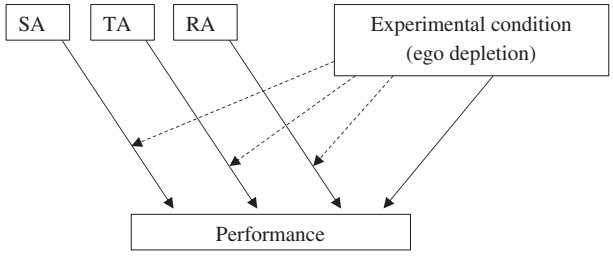

Figure 2. Model diagram including experimental condition as a level 2 predictor (model B). Solid lines indicate the main effects of skill acquisition (SA), transition adaption (TA), reacquisition adaption (RA), and experimental condition on the Stroop task performance. Dashed lines denote the interaction effects (i.e. experimental condition and SA). Similar diagrams could be generated for models C and D, where the experimental condition would be replaced by perceived ego depletion and cognitive abilities, respectively.

indicates the mean value of such a level 2 predictor in the sample. To illustrate, the main effect of cognitive abilities indicates how the intercept changes if the person has above average cognitive abilities (average abilities vs one point above average). Similarly, interactions between cognitive abilities and change parameters indicate how the performance trajectory changes (i.e. learning rate in the pre-change phase) for people with above average abilities. To aid interpretation of the coefficients figures with performance trajectories are also presented.

The variability of performance trajectories and thus the need to include random effects was confirmed in preliminary analyses using R package *kml* (k-means for longitudinal data, version 2.4.1) for longitudinal cluster analysis (Genolini, Alacoque, Sentenac, & Arnaud, 2015; Genolini & Falissard, 2010, 2011). Figure 3 illustrates the differences between the people. Performance trajectories indicate that there was indeed performance impairment due to change but there

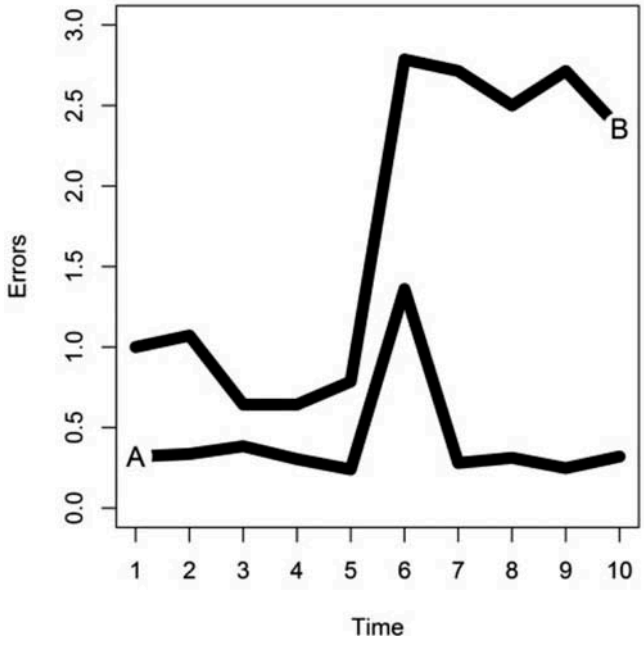

Figure 3. Two mean performance trajectories for errors on the modified Stroop task. The two trajectories were identified using longitudinal cluster analysis (R package *kml*). Most participants (89.9%) showed performance trajectories similar to that of cluster A. Thus, they displayed stable performance in the pre-change phase, but their performance was impaired after being confronted with change after the fifth measurement occasion. Nevertheless, they quickly adapted to change making few errors on next post-change measurement occasions. Only a tenth of the sample (10.1%) showed a performance trajectory similar to that of cluster B, which resembles more the expected adaptive performance curve with quadratic effects.

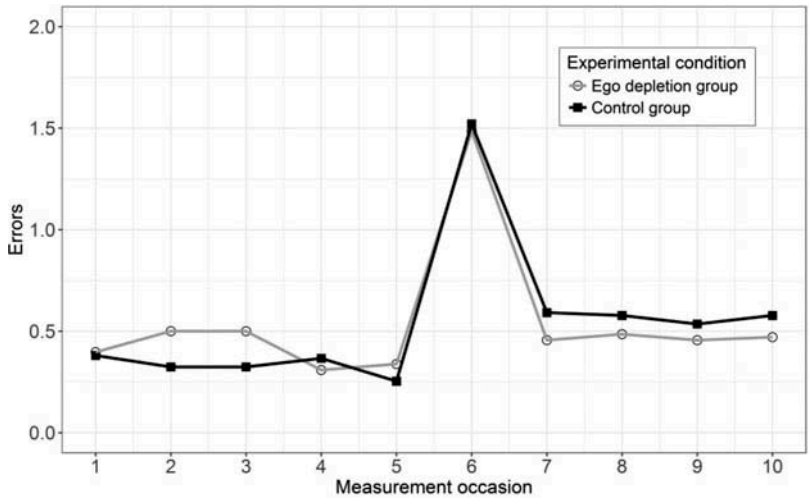

Figure 4. Mean performance trajectories for the two experimental conditions (ego depletion group vs control group). There were only negligible differences between the two groups (see Table 3, model B).

were also differences between the people (cluster A vs cluster B). Moreover, the modified Stroop task was relatively easy for many participants as evidenced by the cluster's A mean number of errors being often close to zero. Such excess of zeros is not unusual for count data (O'Hara & Kotze, 2010). Thus instead of fitting standard mixed-effects models generalized mixed-effects models were fitted using maximum likelihood estimation (Laplace approximation). Specifically, zero-inflated Poisson models with log link function (R package *glmmADMB*, version 0.8.5) were specified, which enable one to account for an excess of zero-count data (see Atkins & Gallop, 2007 for a gentle introduction to modeling count data).

3. Results

3.1. Basic model (A)

Beginning with a simple model with only one fixed effect and random effect (intercept) the model complexity was increased by adding three other fixed effects for the respective change variables (SA, TA, RA) one at a time. Thus, first the SA variable was added, the next model consisted of both SA and TA, etc. Each pair of consecutive models was compared via likelihood ratio tests and consideration of the usual trade-off (deviance reduction vs model complexity) led to the conclusion that the additional parameters can be retained. Next, it was proceeded with adding random effects for the three change variables one at a time as it was done for fixed effects. However, variance of the random effects for TA was undistinguishable from zero after TA was added to a model with a random effect for SA. Therefore, the random effect for TA was dropped from further models. Subsequently fixed effects for quadratic change parameters (SA2 and RA2) were added, but they were not retained. According to the mentioned cluster analysis (Figure 3) curvilinear patterns in performance trajectories were visible only for a small part of the sample. Considering that only negligible deviance reduction was found after adding quadratic variables the increase in model complexity was not tenable. Thus, the final level 1 model was a generalized linear model:

$$E(y_{ij}) = g^{-1}([b_0 + r_{0i}] + [b_{SA} + r_{SAi}]SA_{ij} + [b_{TA}]TA_{ij} + [b_{RA} + r_{RAi}]RA_{ij})$$

where E(yij) is the expected performance of a person (i) on a particular measurement occasion (j). g^{-1} denotes the inverse link function, which is an exponential function in this case (inverse of the log link function). The right-hand side of the equation consists of fixed effects (b), random effects (r) and values of the predictor variables (i.e. SA_{ij}).

Table 3 contains the summary of results for (model A).

3.2. Models with level 2 predictors (B-D)

Expanding the basic model level 2 predictors were added (experimental condition, perceived ego depletion or cognitive abilities), which were of main interest according to the hypotheses (models B-D). To illustrate, for model B (experimental condition, EC) the following level 2 equations were specified:

$$b_{0i} = b_0 + b_{0,EC}EC_i + r_{0i}$$

$$b_{SAi} = b_{SA} + b_{SA,EC}EC_i + r_{SAi}$$

$$b_{TAi} = b_{TA} + b_{TA,EC}EC_i$$

$$b_{RAi} = b_{RA} + b_{RA,EC}EC_i + r_{RAi}$$

Those four equations could be inserted into the simplified level 1 equation in order to predict the performance of individual participants:

$$E(yij) = g^{-1}\left(b_{0i} + b_{SAi}SA_{ij} + b_{TAi}TA_{ij} + b_{RAi}RA_{ij}\right)$$

3.3. Main analyses

Ego depletion. The first set of hypotheses referred to the ego-depletion effect. Thus, before entering the respective predictors it was examined whether objective ego depletion was related to perceived ego depletion. As expected, participants in the ego-depletion condition reported on average a higher level of ego depletion after completing the first task (M = 3.46, SD = 1.30) than participants in the control group (M = 2.83, SD = 1.27), $t(137) = 2.88$, d = 0.49, p = .002. However, perceived ego depletion differences between the ego-depletion group (M = 3.55, SD = 1.59) and the control group (M = 3.52, SD = 1.45) disappeared after the completion of the second task, $t(135) = 0.12$, d = 0.02, p = .451. It can be attributed to the elevated perceived ego depletion in the control group (before vs after the second task). In contrast, perceived ego depletion hardly changed in the ego-depletion condition, which implies that people in both conditions reported similar levels of perceived ego depletion after completing the second task. To test the hypothesis that ego depletion impairs adaptive performance experimental condition (ego depletion group vs control group) and its interactions with SA, TA, and RA were entered into the model. However, no coefficient involving ego depletion was statistically significant (see Table 3, model B). As it can be seen in Figure 4 there were no noteworthy differences between the mean performance trajectories of the two conditions.

3.3.1. Subjective ego depletion

Although people who reported larger ego depletion (vs smaller) after completing the first task (crossing-out-letters) made more errors on the first measurement occasion of the second task (b = 0.21, z = 2.51, p = .012), the influence of perceived ego depletion diminished over time. Thus, contrary to the expectations (hypotheses 2a and 2b) subjective ego depletion wasn't related to transition adaption and reacquisition adaption (see Figure 5 and model C in Table 4 for details).

3.3.2. Cognitive abilities

People with high cognitive abilities tended to show better performance than individuals with lower abilities on the first measurement occasion (b = −0.04, z = −3.43, p = .001). As a result, people with lower cognitive abilities made more profound improvements on consecutive pre-change measurement occasions (b = 0.01, z = 2.82, p = .005). However, as expected high cognitive abilities promoted transition adaption and reacquisition adaption (Hypotheses 3a and 3b, respectively). Specifically, people with high cognitive abilities showed less performance impairment directly after the change, b = −0.04, z = −2.65, p = .004. Furthermore, their learning rate in the post-change phase was of larger magnitude than in the pre-change phase, b = −0.02, z = −2.54, p = .006. The second finding is not surprising, considering that people made hardly any errors in the pre-change phase (See Figure 6 and

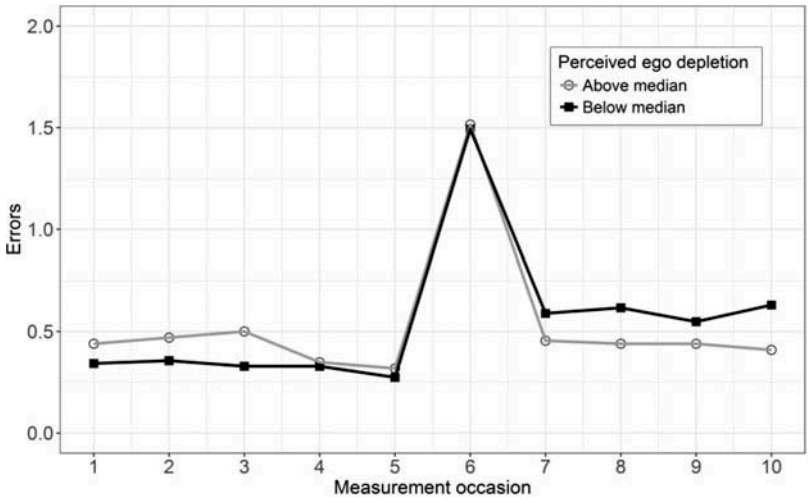

Figure 5. Mean performance trajectories for people with perceived ego depletion above and below the median. Perceived ego depletion variable was dichotomized here for ease of interpretation. The respective model was based on a metric variable, however (see Table 4). According to the model coefficients perceived ego depletion wasn't related to adaptive performance.

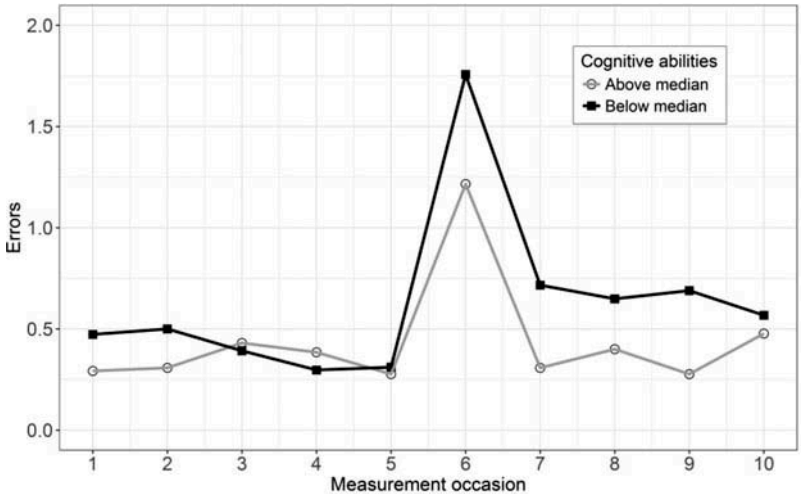

Figure 6. Mean performance trajectories for people with relatively high cognitive abilities and relatively low cognitive abilities. Cognitive abilities were dichotomized here for ease of interpretation. The respective model was based on a metric variable, however (see Table 5). Individuals with high cognitive abilities made generally fewer errors, showed better transition adaption and reacquisition adaption.

Table 5) and therefore couldn't improve much within this phase. In contrast, in the postchange phase a quick performance improvement could be observed after the initial performance impairment. The model including cognitive abilities was the best in the set of considered models according to the Akaike Information Criterion and the respective weights (see Table 6).

Table 6. Comparison of the examined models. Akaike weights *w*(AIC) indicate that the model including cognitive abilities is the best within this set of models

Model	*k*	AIC	Δ(AIC)	*w*(AIC)
Without level 2 predictors (A)	8	2445.98	11.4	0.003
Objective ego depletion (B)	12	2449.80	15.3	<0.001
Perceived ego depletion (C)	12	2442.06	7.5	0.023
Cognitive abilities (D)	12	2434.54	0	0.974

Notes. *k* = number of estimated parameters; AIC = Akaike Information Criterion; Δ(AIC) = Difference between the respective model and the best model with regard to the AIC; *w*(AIC) = Akaike weight, which is based on Δ(AIC) values from all models, it was computed using the R package *bbmle* (version 1.0.2).

4. Discussion

Contrary to the assumptions neither objective nor subjective ego depletion was related to objective adaptive performance scores (errors). Only cognitive abilities were related to performance trajectories in the current study. People with high cognitive abilities showed better transition adaption and reacquisition adaption than individuals with lower abilities. In the following sections the results are discussed in more detail.

4.1. Ego depletion

Although study participants from the ego-depletion group reported higher subjective ego depletion than people in the control group, group membership was neither related to the prechange performance nor the post-change performance. Thus, even though an established (Hagger et al., 2010) depleting task (crossing-out-letters) and a harder version of the commonly used second task (modified Stroop test) were used the objective ego-depletion effect couldn't be replicated. In contrast, subjective ego depletion was at least related to the performance on the first measurement occasion. Specifically, people reporting high subjective ego depletion made more errors. The fact that objective and subjective ego depletion can independently predict performance (Clarkson et al., 2010) was the main reason to include both in the present study. Nevertheless, both variables were not related to performance trajectories in the pre-change phase, which contradicts the ego-depletion theory.

One might argue that the main hypothesis of the present study that ego depletion impairs adaptive performance couldn't be adequately tested because there was already no performance impairment with respect to the pre-change performance. However, differences between the ego-depletion condition and control group were found with respect to the perceived ego depletion before participants were asked to complete the main task. Interestingly, the level of perceived ego-depletion didn't change within the ego-depletion condition when it was assessed after completing the main task. However, participants in the control group reported higher levels of perceived ego depletion after completing the main task than before it. This indicates that the failure to replicate the ego-depletion effect was not due to simplicity of the task. After all, people in the theoretically easier condition experienced a stronger increase in perceived ego depletion. Furthermore, it was already pointed out that a harder version of the Stroop task, which has been frequently used in the ego-depletion research field, was used. It is important to note that another intuitive explanation can also be ruled out. Specifically, one may be inclined to argue that participants in the ego-depletion condition already reached the maximum level of perceived ego depletion rendering further depletion impossible. However, the reported mean subjective depletion is hardly extreme. Thus, experiencing subjective depletion to a greater extent was possible.

It could be argued that the lack of evidence for ego-depletion effect was due to low power of the current study. However, the sample size (N = 139) is almost three times larger than the average sample size (N = 54) found across 198 samples in the ego-depletion metaanalysis of Hagger et al. (2010). Thus, the current sample size was adequate to discover potential effects of ego depletion of even smaller magnitude than those reported in meta-analyses (Carter & McCullough, 2014; Hagger et al., 2010). In order to rule out that the lack of statistically significant effect of ego depletion was due to the chosen longitudinal framework the average performance of both groups before task change was compared using t-test. Although people in the ego-depletion group tended to make more errors (M = 2.04, SD = 2.16) than participants in the control group (M = 1.65, SD = 2.22) the effect was small and statistically non-significant, $t(137) = 1.06$, $d = 0.18$, $p = .144$. After the task change people in the ego-depletion group made even less errors (M = 3.35, SD = 3.31) than people in the control group (M = 3.80, SD = 3.76) but the effect was also small and statistically non-significant, $t(137) = -0.75$, $d = -0.13$, $p = .228$. Thus, the lack of evidence for ego-depletion effect in the current study was neither due study design nor due to statistical analyses. Therefore, in the following paragraphs other explanations of the current results are explored.

The hypotheses implying a relationship between ego depletion and post-change performance were based on many studies where ego depletion was linked to low (pre-change) performance (Hagger et al., 2010). Twenty years ago, as the research devoted to the strength model of self-

control was gaining momentum, Kuhl wrote "*Baumeister and Heatherton's target article on self-regulation failure reminded me of my first attempt to bake bread. My mother had told me all the ingredients but I did not know how to put them together: The result was closer to some sort of cereal pudding than to bread, but grandpa liked it because it was easy to swallow. Because we are still in the childhood years of experimental research on human volition, it is a remarkable achievement to present virtually all the ingredients that seem necessary for a theory of volition and volitional impairment (self-regulation failure). Nonetheless, the authors are far from explaining how all the phenomena they cite make a theory of volition. Such a theory should be able to resolve some of the paradoxes they mention (…)*" (Kuhl, 1996, p. 61). One can argue, whether the harsh treatment was appropriate at that time, but the assumptions of ego-depletion theory have been falsified on many occasions in recent years, as evidenced by the next paragraph.

Several researchers couldn't replicate the ego-depletion effect (i.e. Xu et al., 2014), which previously appeared to be robust according to the meta-analytic findings (Hagger et al., 2010). However, further meta-analyses casted some doubts on the resource model of self-control (Carter, Kofler, Forster, & Mccullough, 2015; Carter & McCullough, 2014). Nevertheless, the approach of Carter and colleagues has been criticized by the proponents of the ego-depletion theory (Cunningham & Baumeister, 2016). However, another meta-analysis (Hagger et al., 2016) based on new preregistered replication attempts yielded no support for existence of the ego-depletion effect (d = 0.04). Thus, if the ego-depletion effect exists it is on average smaller and less robust (Dang, 2017) than initially (Hagger et al., 2010) assumed. The additional cross-sectional analyses in the current study corroborate this assertion (d = 0.18 for pre-change performance and d = −0.13 for post-change performance). Thus, considering the magnitude of the recently reported average effect sizes, one would need samples exceeding 10 000 participants in order to "save" the ego-depletion theory and find evidence for such small effects using cross-sectional studies (Witte & Zenker, 2017). Additionally, search for biological proxies of self-control resources like glucose (Vadillo, Gold, & Osman, 2016) and heart rate variability (Zahn et al., 2016) yielded null or small effects, respectively. Thus, researchers have pointed out that even though the proposed resource or muscle analogy is attractive when describing self-control it cannot account for all findings in this research field (Inzlicht & Berkman, 2015; Mischel, 2014).

However, one shouldn't ignore successful replications of the ego-depletion phenomenon. Therefore, researchers have begun to formulate other explanations or theories, i.e. self-control failure may be a result of attentional shifts, motivational shifts and self-set goals (Inzlicht & Schmeichel, 2012; Wenzel, Zahn, Rowland, & Kubiak, 2016). Furthermore, a dynamic model has been proposed, where the reallocation of resources (based on costbenefit analysis) rather than depletion plays a central role (Kurzban, Duckworth, Kable, & Myers, 2013). Others have pointed out that one's beliefs about availability of willpower can be more important than the actual resource depletion (Job, Dweck, & Walton, 2010; Job, Walton, Bernecker, & Dweck, 2015). Such explanations may account for some unexpected findings or paradoxes, which contradict the resource model of self-control, i.e. alleviating ego depletion with priming effects (Boucher & Kofos, 2012) and results indicating that when confronted with three tasks requiring self-control participants in the ego-depletion group can actually perform better than people in the control group (Converse & Deshon, 2009; Xiao, Dang, Mao, & Liljedahl, 2014).

Interestingly, one research group (Lindner, Nagy, Arhuis, & Retelsdorf, 2017) who adopted a longitudinal design did find differences over time between ego-depletion group and control group. Specifically, the ego-depletion group showed a stronger performance decrease as indicated by the decrease rate (slope). However, the ego-depletion group was descriptively better on the first few trials of the second task and thus was not significantly worse in statistical terms. Furthermore, no differences between the two groups were found with respect to the average performance, which contradicts the usual cross-sectional evidence found for ego-depletion theory. Nevertheless, it has been argued that the dual-task paradigm is not an adequate approach when one wants to reliably evoke ego depletion (Lee, Chatzisarantis, & Hagger, 2016). Furthermore, cross-sectional analyses (average performance) may be regarded as less insightful than longitudinal modeling of performance. However, with regard to the latter suggestion it has to be noted that no longitudinal effects of ego depletion were found in the current

study. In future longitudinal studies, one could investigate whether other explanations (self-set goals, motivational shifts, reallocation of resources, beliefs about own willpower) can better predict performance trajectories than the resource model of self-control.

Although the reliability of the self-reported ego depletion was good in the present study ($\omega_t \geq .86$), it has to be acknowledged that there was some measurement error. Therefore, in the future studies, one could also consider using other statistical methods (structural equation modeling) or frameworks (Bayesian inference). Multilevel modeling and structural equation modeling often lead to the same conclusions, but there is lack of systematic empirical comparisons (Pitariu & Ployhart, 2010; Ployhart & Ward, 2011). Additionally, it could be fruitful to utilize Bayesian inference methods (i.e. Bayesian multilevel modeling) because they enable one to model measurement error explicitly (McElreath, 2016).

4.2. Cognitive abilities

As expected, evidence was found for the assertion that cognitive abilities promote adaptive performance. Strikingly, the mean performance trajectory found for people with high cognitive abilities (Figure 6) resembles the main longitudinal cluster identified in a preliminary analysis (Figure 3). Specifically, those individuals showed relatively small performance impairment directly after the change and quickly reached the pre-change performance level. The fact that the learning rate for those individuals was faster in the postchange phase than in the pre-change phase can be easily explained by the phase-specific starting points. Participants showed good performance already on the first measurement occasions so performance improvement in the pre-change phase was not possible. In contrast, due to the change-related performance impairment, it was possible for them to improve on the consecutive trials of the post-change phase.

The benefits of high cognitive abilities with respect to AP identified in the present study corroborate previous cross-sectional findings (Bell & Kozlowski, 2002; Frank & Kluge, 2017; Keith et al., 2010). Nevertheless, the few previous longitudinal investigations yielded mixed results (Howe, 2019; Lang & Bliese, 2009; Wheeler, 2012). Lang and Bliese (2009), who developed the longitudinal adaptive performance framework found detrimental relative effects of high cognitive abilities. One may argue that their task—a tank battle scenario—was more complex than the modified Stroop task and that the relationship with AP depends on task complexity. However, although Howe (2019) used a task more complex than ours (stock pricing simulation) he also found that high cognitive abilities promote adaptive performance.

Furthermore, Wheeler (2012) found that task complexity didn't moderate the relationship between cognitive abilities and AP. Based on meta-analytic findings regarding other performance constructs (Hunter & Hunter, 1984; Judge, Jackson, Shaw, Scott, & Rich, 2007; Lang, Kersting, Hülsheger, & Lang, 2010; Schmidt & Hunter, 2004, 1998) one may be inclined to believe that detrimental effects of cognitive abilities are not feasible. Even if for some performance constructs—e.g. counterproductive behavior and self-rated personal initiative—the relationship is very small or non-existent (Gonzalez-Mulé, Mount, & Oh, 2014; Tornau & Frese, 2013) there is no overwhelming evidence of detrimental effects. In the extant literature, there is not much evidence supporting the "less-is-more" hypothesis (Beier & Oswald, 2012). Nevertheless, as it was pointed out in the introductory sections, there are isolated cross-sectional findings consistent with the longitudinal results of Lang and Bliese (i.e. Blickle et al., 2011; Chan & Schmitt, 2002). Furthermore, a small detrimental effect of cognitive abilities on the learning rate in the pre-change phase was found. However, it is probably due to the fact, that people with high cognitive abilities rapidly reached the maximum performance level and thus couldn't improve anymore. In contrast, persons with lower abilities made on average more errors on the first measurement occasion so they could still improve on the consecutive trials. Other researchers are encouraged to systematically examine possible explanations for the mixed patterns found in longitudinal studies. In the study reasoning rather than crystallized intelligence (Cattell, 1963; Horn & Cattell, 1966) was used as an indicator of cognitive abilities. In the future, one could examine ability type as a potential moderator of the relationship between cognitive abilities and adaptive performance. Other explanations for the mixed findings could include task or sample characteristics.

5. Conclusion

The findings do not yield support to the assertion that ego depletion impairs adaptive performance. Utilizing a longitudinal framework (Lang & Bliese, 2009; Niessen & Jimmieson, 2016) no evidence for negative effects of objective or subjective ego depletion was found. Moreover, only perceived ego depletion was related to initial performance. Even though people in the ego-depletion condition reported ego depletion to a greater extent than people in the control group and a harder version of the frequently utilized task to gauge the ego-depletion effect was used, the experimental group and the control group showed comparable performance levels both before and after the change occurred. The results are consistent with emerging evidence (i.e. Hagger et al., 2016) that the ego-depletion effect is not as robust as it has been assumed (Hagger et al., 2010) and that comparing self-control to muscles or limited resources is problematic. The volatility and duration of the ego-depletion effect implies also that it shouldn't be feared outside laboratory situations (i.e. at work), because it can be easily avoided or overcome by taking short breaks when dealing with tasks that require self-control. Finally, it could be confirmed that high cognitive abilities promote adaptive performance (task-related accuracy). Interestingly, people with high cognitive abilities could quickly adapt to change as they were able to reach pre-change levels of performance immediately after the short-term change-induced performance impairment. Nevertheless, further research is needed in order to explain mixed longitudinal findings in the adaptive performance research field (Howe, 2019; Lang & Bliese, 2009; Wheeler, 2012). It may be fruitful to examine performance trajectories with different types of samples (i.e. employees) and to consider other measures of AP (e.g. situational interviews) in the future studies. Further avenues include modeling dynamic relationships where not only the performance but also predictors change with time (Pitariu & Ployhart, 2010), i.e. state personality variables. Potential candidates for such variables are goal-monitoring (Harkin et al., 2016) and mind-wandering (Randall, Oswald, & Beier, 2014). The latter has been linked to worse performance due to the allocation of resources, but it isn't clear whether the same holds true for adaptive performance. Finally, one could also examine how adaptability changes across the life span and whether the changes are similar to those identified for job performance (Alessandri & Borgogni, 2015).

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Supplementary materials

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