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Executive Functions Neither Associated With Agentic Extraversion nor Sensitive to the Dopamine D2 Blocker Sulpiride in a Preregistered Study

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Supplementary Materials: Data, Materials, Preregistration [see Index of Supplementary Materials]

Abstract

Initial studies suggest that extraversion and executive functions (EFs) are associated because of shared dopaminergic mechanisms. Aiming to conceptually replicate these findings we conducted a preregistered study to investigate (1) associations between extraversion and performance in three tasks (3-back, switching, AX-CPT) and (2) whether these associations are sensitive to administration of the dopamine D2 receptor blocker sulpiride in a placebo-controlled between-subjects design (N = 200). Against expectations, neither (agentic) extraversion, nor its interaction with substance condition explained performance in any of the EF tasks. As the current results are limited by an unexpectedly low reliability of the measures derived from the switching task and the AX-CPT, further preregistered studies using psychometrically superior measures are needed.

Keywords

stability-flexibility, dopamine, extraversion, executive functions

Relevance Statement

We investigated potential dopaminergic associations between extraversion and executive functions with an improved protocol in a preregistered, higher powered study, using a higher number of executive functioning tasks.

Key Insights

- Trait extraversion could not explain performance in executive functioning tasks.
- Sulpiride X extraversion interactions could neither explain task performance.
- We discuss methodological problems of frequently used executive functioning tasks.
- We offer alternative approaches regarding reliability problems for future studies.

Executive functions (EFs) describe a set of high-level cognitive mechanisms which regulate lower-level mechanisms for goal-directed behavior (Friedman & Miyake, 2017), for instance by adaptively stabilizing and updating working memory representations, sometimes dubbed the stability-flexibility balance (Paul et al., 2021). Interestingly, several studies suggest that EFs, and stability-flexibility in particular, are associated with the non-cognitive trait of extraversion (Campbell et al., 2011; Lieberman & Rosenthal, 2001; Wacker, 2018). Concerning mechanisms underlying this association, Lieberman and Rosenthal (2001) argued that better updating of representations might be advantageous in social situations, as the resulting higher flexibility might allow for better multitasking and thus more skillful social interaction, prompting the idea of stability-flexibility being one explanatory mechanism behind extraverts' higher sociability. Alternatively, individual differences in incentive motivation, which are thought to partly underlie trait extraversion (Depue & Collins, 1999), might not only lead to higher motivation and reward sensitivity in social situations, but also in cognitive performance contexts (Westbrook et al., 2021). The association between extraversion and stability-flexibility might therefore be due to extraverts' higher motivation for good task performance (Wacker, 2018).

Intriguingly, both explanations are compatible with the idea that individual differences in brain dopamine (DA) constitute a shared neural dimension underlying the observed association: Striatal DA pathways have been found to partly regulate stability-flexibility (Cools, 2019). Extraversion, especially its agentic facet encompassing assertiveness, activity, and having a sense of accomplishing goals, has likewise been associated with (striatal) DA both theoretically (Depue & Collins, 1999) and empirically (Baik et al., 2012; Lai et al., 2019; Wacker & Smillie, 2015). Most notably, several pharmacological studies found that dopaminergic drugs altering striatal D2 receptor activation, such as sulpiride or bromocriptine, affect EF task performance differently depending on baseline cognitive functions and striatal DA signaling (Cools, 2019; Fallon et al., 2019; Westbrook et al., 2021). The effects of the same dopaminergic drugs on performance in EF tasks, like

the n-back working memory task and AX-continuous performance task, have been found to differ depending on (agentic) extraversion (Wacker, 2018; Wacker et al., 2006).

Whereas previous studies on extraversion-related differences in dopaminergic drug effects on EFs are suggestive, they are also limited by several weaknesses. Firstly, they were performed with relatively small samples without preregistration, possibly making them underpowered and reported effects inflated. Secondly, most of these studies applied only one EF task to investigate individual differences in stability-flexibility (Wacker, 2018), which can pose a problem because EF tasks operate on lower-level mechanisms (i.e. processing of letters, colors or numbers) potentially causing additional systematic variation in performance. For example, previously reported extraversion-EF associations could theoretically stem from extraversion-related individual differences in faster processing of letters. Thirdly, although different EFs are dissociable on a behavioral level by distinct variation in EF task performance ("diversity"), they also share variance ("unity"; Friedman & Miyake, 2017). Applying only one task per study poses the problem that shared variance among EF tasks leaves it unclear whether a potential association is as specific as expected. Finally, effects of other potential variables associated with DA or EF performance were not always measured or reported. Most notably, DA has also been theorized to be associated with openness to experience (DeYoung, 2013)—a trait moderately associated with both extraversion and cognitive performance/intelligence (e.g. Ashton et al., 2000; Käckenmester et al., 2019). Indeed, a previous publication based on different parts of the current study's dataset found that openness modulated dopaminergic drug effects on creativity (Käckenmester et al., 2019), for which stability-flexibility is a key process (Nijstad et al., 2010). To attribute potential effects on extraversion, it is therefore important to control for trait openness.

The Current Study

We aimed to overcome limitations of previous research by conducting the present, more highly powered study with an improved protocol and preregistered methods, hypotheses and analyses (see Supplementary Materials). More specifically, we applied three EF tasks which operate on slightly different lower-level processes and target stability-flexibility of working memory representations with different approaches, aiming to investigate whether potential associations of extraversion with task performance are task-specific or whether they can be explained by shared cognitive processes among tasks (Herrmann & Wacker, 2021). By increasing the number of tasks and sample size, we aimed to replicate and extend previous findings by testing (1) the association between (agentic) extraversion and performance in three previously used EF tasks (3-back, switching, and AX-CPT), (2) the modulation of these associations by a pharmacological manipulation of dopamine functioning, and (3) the correlation among task performances in the three EF tasks. For each EF task measure, we applied a regression model to test the confirmatory hypothesis that task performance is significantly explained by an interaction between

substance condition and agentic extraversion (and task condition, except for 3-back). In addition, we systematically explored potential confounding effects of trait openness and fluid intelligence (i.e., a well-established correlate of EFs, e.g. Dang et al., 2014).

Method

Participants and Design

We recruited 210 male, right-handed, physically and mentally healthy participants aged between 18 and 35 years (M = 25.0; SD = 3.8), who either received a 200 mg capsule of the DA D2-receptor antagonist sulpiride or a non-distinguishable placebo for oral consumption in a randomized, double-blind between-subjects design. Ten participants were excluded because they did not follow instructions in the current three tasks (6), were unable or arrived too late to swallow the capsule (3), or had incomplete data due to technical failure (1; n = 100 per condition). As opposed to a previous study on a female sample (Herrmann & Wacker, 2021; Wacker, 2018), we restricted the current sample to male participants to probe generalizability across the sexes while still controlling for potential sex-specific differences in metabolization of sulpiride. Although sulpiride is a DA antagonist, low dosages have been demonstrated to have agonistic (activating and antidepressant) effects, which is ascribed to sulpiride's high affinity to presynaptic DA autoreceptors (vs. postsynaptic DA receptors for higher dosages; Mauri et al., 1996). To ensure maximum safety for participants, we individually assessed strict exclusion criteria in a pretesting and excluded participants with psychiatric disorders assessed in a standardized clinical interview (Mini-DIPS; Margraf et al., 2017), measured blood pressure higher than 140/90, self-reported lifetime medical conditions (especially epilepsy, endocrinopathies, hypertension, coronary heart disease, bleeding or other bowel diseases, liver or kidney diseases), consumption of prescription medication, illegal drugs (last 3 months) or cigarettes (> 10 per week), or known allergies to any psychoactive substances. The study was approved by the Human Research Ethics Committee of the German Society for Psychology. Participants were tested in groups of three or four and reimbursed with 70€ (or course credit) for six hours of participation. As this study included several tasks, our sample size was determined by the general goal to have a power of 80% to find an interaction in an ANCOVA with small to medium effect size of f = 0.2 (α = .05), two groups (substance conditions) and one covariate (one personality trait, in this case agentic extraversion) using G*Power 3 (Faul et al., 2007).

Procedure

After checking eligibility, participants' personality was assessed in a pretesting with the German translation of the NEO-PI-3 (Costa & McCrae, 2010), using the mean of its assertiveness and activity facets to operationalize agentic extraversion (Wacker, 2018). At

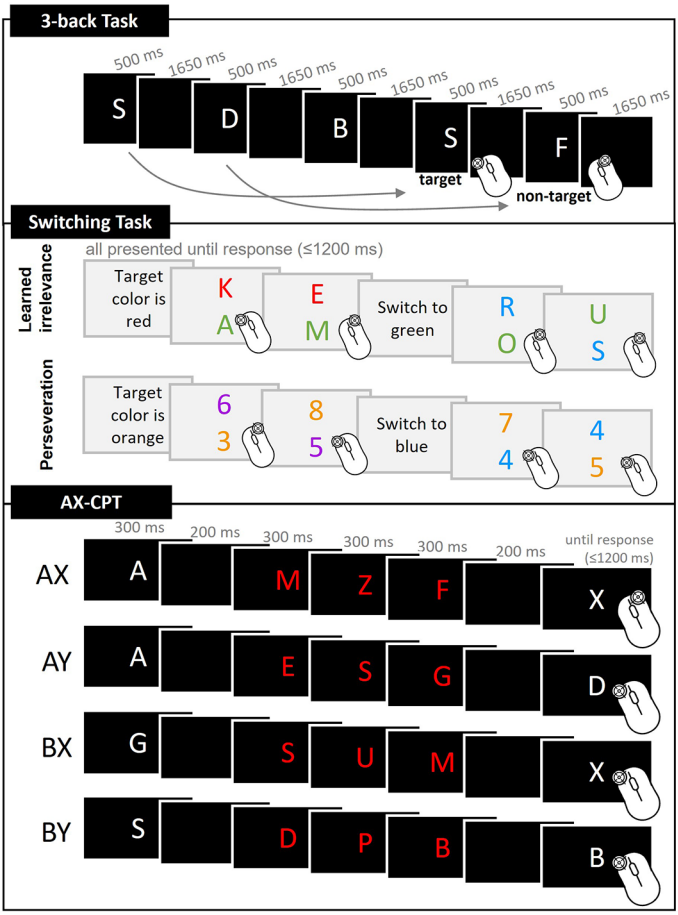
the main testing (9:30 AM), participants took their assigned capsule (intake time *M* = 9:39 am, *SD* = 5 min) and received a light, standardized breakfast before crystallized and fluid intelligence was assessed with the intelligence structure battery (INSBAT; Arendasy et al., 2012) within *M* = 1.2 hours (*SD* = 0.2). Among the following series of tasks, the AX-CPT came third at *M* = 12:07 pm (*SD* = 13 min), followed by switching (*M* = 12:33 pm, *SD* = 14 min), and 3-back (*M* = 12:47 pm, *SD* = 14 min). After three further tasks not relevant to the current research questions participants were debriefed, thanked, and reimbursed.

Measures

Figure 1 provides an overview of the three EF tasks. In the 3-back, participants completed 57 practice trials and then 117 trials in a fixed random order with each consecutive trial consisting of one white letter on a black screen (500 ms), followed by a pause (1650 ms). Participants were instructed to indicate whether the currently presented letter was identical to the letter 3 trials earlier (40 target trials) or not (77 non-target trials; including 12 trials as 1- and 2-back to prevent answering based on familiarity). Answers were provided via mouse-click (left for "yes", right for "no"), while fast and accurate performance was reinforced with standardized verbal feedbacks (350 ms) after each trial ("correct", "incorrect", "slow"). "Slow"-feedback was given based on the individual latency criterion of the 90th percentile of a participant's reaction time (RT) distribution in the last 50 practice trials to reduce variation in potential speed-accuracy-tradeoffs (cf. Wacker et al., 2006).

Figure 1

Exampe Trials Depicting Within-Subject Conditions of the Three EF Tasks



Note. Example trials of the three EF tasks with different within-subject conditions. Grey numbers refer to stimulus presentation times. Each mouse icon signifies the correct reaction for one trial (left or right click). 3-back task: The first three trials cannot be classified because there are no preceding trials. Letters in (non-)target trials are (not) identical to the letter three trials earlier (as indicated by grey arrows). Switching Task: Learned irrelevance: The previous distractor color becomes the new target color, and a new color becomes the distractor color. Perseveration: A new color becomes the target color, and the previous target color becomes the distractor color. AX-CPT: The highly frequent AX-trials induce a strong bias for right mouse-clicks, producing a larger response latency especially in AY-trials. Red letters signify distractors. Catch trials are omitted from the figure.

The 3-back task requires participants to continuously buffer new information with the goal to measure working memory updating (Herrmann & Wacker, 2021). For better com-

parison with previous studies the analysis focus is on target trials, for which we analyzed mean accuracy (correct vs. incorrect) and mean reaction times of correct responses.

The switching task started with 20 practice trials in which participants identified single letters as vowel/consonant or numbers as odd/even, and then continued with six 60-trial blocks with pairs of colored letters (A/E/O/U/K/M/R/S) or numbers (2/3/4/5/6/7/8/9). These were presented in alternating order with the instruction to identify the stimulus in the target-color as vowel/consonant or odd/even (right/left mouse-click, respectively) and ignore the stimulus in the distractor-color, responding as fast and correctly as possible. Target- and distractor-colors were defined per block at the beginning (e.g. "target color is red") and at the "switch" of colors after 40 trials (e.g. "switch to green"). Stimuli were presented until the participant responded, followed by a 1000-ms (2000-ms) pause for correct (incorrect) responses to foster low error rates.

In "learned irrelevance" blocks the pre-switch *irrelevant* distractor-color became the post-switch target-color, and a new color became the distractor-color. Stability is assumed to be advantageous in this condition because it better shields from distraction by the new color of the distractor, leading to lower switch costs, whereas flexibility (going along with a stronger bias towards new stimuli) leads to more distraction by the new color of the distractor (Müller et al., 2007). In "perseveration" blocks the pre-switch target-color was changed to be the post-switch distractor-color (fostering *persevered* attention to irrelevant stimuli), and a new color became the post-switch target-color. Flexibility is assumed to be advantageous is this condition because (1) faster disengagement from the pre-switch target color leads to less distraction when it becomes the post-switch distractor-color, and (2) the new color is more easily updated as target-color. In contrast, stability is assumed to be disadvantageous because (1) the higher "stickiness" (Chatham et al., 2011) of the pre-switch target-color leads to more distraction when that color becomes the post-switch distractor-color, and (2) the new color is not as easily updated as target-color (Müller et al., 2007). We analyzed mean RTs for five correct trials pre- versus post-switch ("switch costs") as a measure for the ease of shifting attention, with higher flexibility being indicated by higher switch costs in the learned irrelevance condition, and lower switch costs in the perseveration condition.

The AX-CPT was identical to the one used by Wacker (2018) but without a manipulation of affect. After written instructions and 10 practice trials, two 105-trial blocks were presented in separately pseudorandomized order. Each trial started with a white cue (300 ms) on black background (for 80 trials A, for 25 trials a letter from this list: B/D/E/F/G/M/P/S/U/Z), followed by an interstimulus interval (200 ms), three randomly selected red distractors from the list above (300 ms each), another interstimulus interval (200 ms), and the white probe (X or one letter from the list above) or the words "right-click" (in 5 "catch" trials per block) presented until response (≤ 1200 ms). Responses were given via mouse with the instruction to respond as fast and accurately as possible with a right-click whenever cue A was followed by the probe X (160 "AX trials"), and left-click

whenever cue A was followed by a probe other than X (20 "AY trials"), or when a cue other than A was followed by the probe X (20 "BX trials") or other than X (20 "BY trials"). Catch trials were included so responses in B-trials were not predefined by cue B.

We analyzed median RTs for correct trials in the within-subject conditions AY and BXBY (average of BX and BY). A lower AY-score is assumed reflect flexibility, because the lower maintenance of the cue reduces the bias towards the AX-condition. A lower BXBY-score is assumed to reflect stability, because the higher maintenance of the B-cue leads to a stronger bias towards left-clicking, which happens four times more often than right-clicking (only in catch trials), making this bias advantageous (Dreisbach, 2006).

Data Analysis

We analyzed 3-back performance with linear regression models, and switching and AX-CPT performance with linear mixed models. RT-based measures except for difference scores were log10-transformed to normalize distributions. We included substance condition, agentic extraversion (centered within substance condition), and task condition (except for 3-back) and their interactions as fixed effects predictors, and the respective summary indices as outcomes (3-back: mean target RTs, mean target accuracy; switching: mean RTs pre and post switch per switching condition; AX-CPT: median RTs AY and BXBY). We analyzed summary indices per condition (and not trial RTs or trial accuracy) to facilitate comparisons with previous studies on associations between extraversion and task performance. In mixed models we additionally included a random intercept for participant (the preregistered summary indices left us with one observation per within-subject condition, which is why we did not include random slopes; Barr, 2013). Because stimulus content (numbers/letters) differed between switching task blocks, we controlled for block number and stimulus content. We fitted the linear mixed models with a restricted maximum-likelihood estimation, and used the Satterthwaite's approximation to obtain *p*-values. In preregistered exploratory analyses, we either included fluid intelligence or one of the NEO scales (most notably openness) as covariates, and investigated pairwise correlations among the tasks.

Transparency, Openness, and Reproducibility

We preregistered methods, hypotheses, analyses (see Supplementary Materials), and a list of all measures (see Supplementary Materials) in 2017 after collecting 70 datasets and before accessing any of the data. The analysis was performed as preregistered, except for an additional exploratory analysis of behavioral ratings from a discussion task at the end of the experiment which will be reported elsewhere as it is unrelated to the current research questions. Open preprocessed and raw data, reproducible analysis scripts, and a codebook are permanently available in the Supplementary Materials. All other preregistered analyses on this dataset, focusing on the respective other cognitive

tasks of the study, have been published by Ohmann et al. (2020), Käckenmester et al. (2019), and Smillie et al. (2021; Experiment 2).

Results

Preliminary Analyses

Descriptive statistics of demographics, personality, and intelligence per substance condition and in total are displayed in Table 1. The two substance conditions did not differ significantly in age, weight, height, personality, intelligence (all *p*s > .12, see Table 1), or substance condition guess ($\chi^2(1) = 0.09$, $p = 0.76$). Correctness of substance condition guess was independent from guessed substance condition ($\chi^2(1) = 0.02$, $p = 0.89$) and individual confidence in the substance condition guess ($\chi^2(3) = 2.22$, $p = 0.53$).

Table 1

Demographic Characteristics, Personality and Intelligence per Substance Group and in Total

	Placebo		Sulpiride				Total	
Variable	***M***	***SD***	***M***	***SD***	***t***	***p***	***M***	***SD***
Demographics								
Age	24.74	4.00	25.25	3.66	-0.92	0.36	24.99	3.83
Weight	80.39	11.53	79.47	10.60	0.59	0.56	79.93	11.06
Height	183.16	7.67	181.79	7.33	1.28	0.20	182.47	7.51
NEO scales								
Neuroticism	2.50	0.44	2.50	0.40	-0.10	0.92	2.50	0.42
Extraversion	3.34	0.34	3.35	0.37	-0.22	0.82	3.34	0.36
agentic	3.17	3.17	3.17	3.17	-0.13	0.90	3.17	3.17
affiliative	3.37	3.37	3.39	3.39	-0.29	0.77	3.38	3.38
Openness	3.56	0.40	3.54	0.33	0.21	0.84	3.55	0.37
Agreeableness	3.30	0.37	3.31	0.39	-0.17	0.86	3.31	0.38
Conscientiousness	3.38	0.43	3.41	0.39	-0.59	0.56	3.40	0.41
Intelligence								
fluid	113.7	15.63	116.9	13.29	-1.55	0.12	115.3	14.56
crystallized	101.8	13.62	101.5	12.18	0.18	0.86	101.6	12.89

Note. $N = 200$ ($n = 100$ per substance group). Intelligence scores displayed here are normed values but all analyses were computed with raw values.

Based on previously used criteria (Herrmann & Wacker, 2021), we excluded 3-back data if participants failed to respond in > 35% of all trials (14) or failed to react within their individual response window in > 25% of all trials (2). For the switching task we made

blockwise exclusions if mean scores could not be calculated due to less than two correct trials in the response window (150–2000 ms) and excluded data of five participants completely because this left them with less than two blocks per condition. We excluded AX-CPT data of 32 participants due to high error rates (> 50%; 22), reacting too slowly (> 1200 ms in > 50% of the trials; 2), or ignoring the "right-click" instruction in the catch-trials (error rate ≥ 80%; 8), leading to generally invalid B-trials.

Reliability, computed as the Spearman-Brown corrected correlation between the first and second task halves/blocks, was good for 3-back mean target RTs (*Rel.* = .90), accuracy (*Rel.* = .82), and for both AX-CPT conditions (AY: *Rel.* = .85, BXBY: *Rel.* = .84), but low for their difference (AY-BXBY, *Rel.* = .52). Internal consistency among blocks was good for switching mean RTs (pre-switch: Cronbach´s α = .83; post-switch: Cronbach´s α = .81), but very low for difference scores (switch costs: Cronbach´s α = .23, switch cost difference between switching conditions: Cronbach´s α = .27). The low reliability of the difference scores can most likely be ascribed to the high correlation between pre- and post-switch mean RTs (learned irrelevance: $r(196) = .69$, 95% CI [.61, .76], $p < .001$; perseverance: $r(197) = .62$, 95% CI [.53, .70], $p < .001$), and between AY- and BXBY-scores ($r(196) = .64$, 95% CI [.55, .72], $p < .001$), in combination with their good, albeit not perfect, reliabilities (Trafimow, 2015).

Main Analysis

In our preregistered confirmatory analysis, we did not find the expected highest-order interactions for any of the measures (see Table 2). A significant main effect of substance suggested lower 3-back accuracy under sulpiride versus placebo ($t(182) = 2.041$, 95% CI [0.18, 10.83], $p = 0.043$, for *M* and *SD* see Table 3) although this effect should be interpreted with caution as it was not predicted.

Table 2

Linear (Mixed) Models for Task Performance

			95% CI		
Effect	***B***	***SE***	***LL***	***UL***	***p***
3-back Mean Target RTs					
Intercept	2.81	0.008	2.794	2.827	**< .001**
Substance[a]	-0.002	0.008	-0.018	0.015	.820
aE	0.000	0.019	-0.038	0.038	.994
Substance * aE	0.005	0.019	-0.033	0.043	.797
3-back Accuracy					
Intercept	49.567	1.356	46.892	52.242	**< .001**
Substance[a]	2.749	1.356	0.073	5.424	**.044**
aE	0.442	3.146	-5.766	6.650	.888

Effect	*B*	*SE*	95% CI *LL*	95% CI *UL*	*p*
Substance * aE	1.143	3.146	-5.065	7.351	.717
Switching Task					
Intercept	2.8755	0.0060	2.8637	2.8872	< **.001**
Block	-0.0070	0.0010	-0.0089	-0.0052	< **.001**
Num/Let[b]	-0.0048	0.0016	-0.0080	-0.0016	**.004**
Pre-post[c]	-0.0159	0.0016	-0.0190	-0.0127	< **.001**
Cond[d]	0.0003	0.0016	-0.0029	0.0035	.855
Pre-post * cond	-0.0092	0.0050	-0.0189	0.0006	.069
Substance[a]	0.0098	0.0117	-0.0130	0.0326	.402
aE	-0.0019	0.0016	-0.0050	0.0013	.250
Pre-post * substance	-0.0034	0.0016	-0.0066	-0.0003	**.035**
Cond * substance	0.0029	0.0016	-0.0003	0.0061	.077
Pre-post * aE	0.0000	0.0038	-0.0074	0.0074	.994
Cond * aE	-0.0003	0.0038	-0.0077	0.0072	.946
Substance * aE	0.0095	0.0117	-0.0132	0.0323	.416
Pre-post * cond * substance	0.0006	0.0016	-0.0025	0.0038	.702
Pre-post * cond * aE	0.0023	0.0038	-0.0051	0.0097	.546
Pre-post * substance * aE	-0.0062	0.0038	-0.0136	0.0012	.101
Cond * substance * aE	0.0016	0.0038	-0.0059	0.0090	.680
Pre-post * cond * substance * aE	0.0007	0.0038	-0.0068	0.0081	.863
AX-CPT					
Intercept	2.7151	0.0064	2.7027	2.7275	< **.001**
Cond[e]	0.0575	0.0031	0.0515	0.0636	< **.001**
Substance	-0.0047	0.0064	-0.0171	0.0077	.462
aE	-0.0153	0.0144	-0.0433	0.0127	.290
Cond * Substance	-0.0031	0.0031	-0.0091	0.0030	.325
Cond * aE	0.0088	0.0070	-0.0048	0.0225	.210
Substance * aE	-0.0017	0.0144	-0.0297	0.0263	.905
Cond * Substance * aE	-0.0038	0.0070	-0.0174	0.0099	.593

Note. N = 177 (3-back task), N = 196 (switching task), N = 164 (AX-CPT). CI = confidence interval; *LL* = lower limit; *UL* = upper limit; aE = agentic extraversion. Significant effects in bold, within-subject predictors indented, effects central to our hypotheses (highest-order interactions) shaded in grey.
[a]1 = placebo, -1 = sulpiride. [b]1 = letters, -1 = numbers. [c]pre-post switch: 1 = pre, -1 = post. [d]switching condition: 1 = learned irrelevance, -1 = perseveration. [e]trial condition: 1 = AY condition, -1 = BXBY condition.

The switching task and AX-CPT showed within-subjects effects across all participants, indicating that the task conditions had the expected effects on RTs reflected by switch costs (M = 51.3, SD = 85.5, $t(198)$ = 8.471, 95% CI [39.39, 63.29], p < .001), and respectively, longer RTs in AY- (M = 602.1, SD = 114.3) than BXBY-trials (M = 469.2, SD = 117.0, $t(167)$ = 17.655, 95% CI [118.06, 147.78], p < .001). In the regression model, switch costs also

tended to differ between substance conditions, with lower costs in the sulpiride versus placebo condition (sulpiride: M = 41.7, SD = 96.1; placebo: M = 61.1, SD = 72.4), although this effect was nonsignificant when comparing the conditions directly ($t(184)$ = 1.61, 95% CI [−4.4, 43.2], p = .11).

In our preregistered exploratory analysis, we included fluid intelligence as a covariate. All exploratory results can be viewed as R markdown output from our open analysis (see Supplementary Materials). We found significant main effects of fluid intelligence on all measures except 3-back mean target RTs (3-back accuracy: B = 8.447, 95% CI [4.980, 11.974], p < .001; switching: B = −0.026, 95% CI [−0.038, −0.013], p < .001; AX-CPT: B = −0.027, 95% CI [−0.043, −0.012], p = .001). For switching, we found significant three-way interactions of agentic extraversion with fluid intelligence and switching condition (B = 0.013, 95% CI [0.003, 0.022], p = .010), as well as with substance in pre- versus post-switch trials (B = −0.009, 95% CI [−0.019, −0.001], p = .050), which were not predicted and are difficult to interpret due to the lack of substance or switching condition effects, respectively. Apart from a marginally significant three-way interaction of fluid intelligence with substance condition and agentic extraversion for 3-back mean target RTs (B = −0.048, 95% CI [−0.097, 0.001], p = .055), all other interactions with fluid intelligence in any of the models were nonsignificant (p > .105). Furthermore, neither openness nor any other NEO scale, or their interaction with substance, had significant effects on any of the tasks (all ps > .10 for uncorrected highest-order effects involving openness; ps > .90 for all NEO scales and their interactions when controlling the family-wise error rate by Holm-correcting for all statistical tests per task).

All pairwise raw correlations are displayed in Table 3 (along with significance tests, controlling for the family-wise error rate by Holm-correcting within substance group). The pattern of results was nearly identical after partialling out fluid intelligence. Switching and AX-CPT difference scores were computed to reflect condition differences hypothesized to be associated with extraversion (Variables 7 and 10 in Table 3). As an alternative to the AX-CPT difference score we further report the commonly used signal detection theory measures d' context, and A-cue bias (cf. Gonthier et al., 2016; Macmillan & Creelman, 1990). 3-back RTs and accuracy correlated significantly in the sulpiride condition, indicating a speed-accuracy tradeoff, while the correlation in the placebo condition was nonsignificant after Holm correction. Apart from a significant positive correlation between 3-back accuracy and fluid intelligence in the placebo condition, the 3-back task showed no associations. Switching and AX-CPT only showed significant correlations for absolute RT measures, but not for difference scores, indicating that associations among tasks might rather be ascribed to more general individual differences in response latencies than stability-flexibility.

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Table 3

Pairwise Correlations Between the Main Variables for the Two Substance Conditions

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M			665	52.3	757	61.3	735	53.1	6.70	592	466	125	-0.01	-0.05	3.17	3.34	115
SD			171	18.4	154	101	138	116	141	111	114	87.5	1.38	0.51	0.40	0.34	15.6
1. 3-back target RTs	670	177		.36	.14	-.07	.07	.06	-.10	.15	.12	.04	.01	.00	.02	-.04	.14
2. 3-back target accuracy	46.8	18.2	**.42****		-.22	-.12	-.13	.14	-.19	-.15	-.10	-.03	.09	-.04	.03	.04	**.43****
3. LI post RT	765	132	.06	-.23		.32	**.67*****	-.04	.28	**.44****	.35	.12	-.06	-.05	.12	.02	-.29
4. LI switch costs	48.0	127	.06	.15	**.36***		.10	.17	**.66*****	-.16	-.18	.02	.31	.10	.08	.03	-.07
5. PE post RT	767	146	.17	-.10	**.58*****	.05		.36	-.20	**.40***	.29	.13	.03	-.13	.18	.12	-.27
6. PE switch costs	35.5	134	.13	.04	-.07	.09	**.40****		**-.73*****	-.13	-.22	.14	.14	-.08	.13	.09	-.02
7. Switch cost difference	12.6	176	-.06	.08	.31	**.65*****	-.27	**-.70*****		-.02	.04	-.10	.19	.11	-.04	-.04	-.03
8. AY RTs	613	117	.12	-.27	**.60*****	.06	**.61*****	.02	.03		**.69*****	.36	-.09	-.06	-.06	-.05	-.23
9. BXBY RTs	472	121	.02	-.22	**.44****	.04	**.40***	.06	-.02	**.58*****		**-.41***	-.01	-.04	-.09	-.12	-.19
10. AY-BXBY	141	107	.16	.01	.16	.06	.21	-.08	.11	**.42***	**-.48****		-.13	-.05	.05	.10	-.03
11. d' context	0.20	1.19	.09	.06	-.09	.09	-.05	-.08	.13	-.19	-.22	.10		**.48****	.08	.00	.20
12. A-cue bias	-0.02	0.44	-.18	-.17	-.08	.06	-.14	-.14	.16	-.16	-.28	.13	**.75*****		-.09	-.15	.06
13. NEO aE	3.17	0.46	-.02	-.02	-.06	-.13	-.01	-.06	-.05	-.01	-.12	.11	.10	.20		**.78*****	-.06
14. NEO E	3.35	0.37	-.11	.00	-.16	-.12	-.06	-.01	-.08	-.13	-.21	.07	.06	.14	**.82*****		-.03
15. Fluid intelligence	117	13.3	.00	.24	-.32	-.05	-.21	-.03	-.02	-.33	-.15	-.18	.26	.05	-.04	.05	

Note. Data from placebo and sulpiride condition are shown above and below the diagonal, respectively. Significant correlations in bold. Descriptive statistics for fluid intelligence are displayed in normed values but all analyses were computed with raw values. 3-back (1.-2.): target RTs = mean RTs in correct target trials, target accuracy = mean accuracy in target trials. Switching (3.-7.): LI = Learned irrelevance condition, PE = perseveration condition, post = mean RTs after the switch, switch costs = mean RTs after minus before the switch, switch cost difference = switch costs of LI minus PE. AX-CPT (8.-12.): AY RTs = Median RTs of the AY-condition, BXBY RTs = median RTs of the BX and BY conditions, AY-BXBY = difference between the two conditions (AY minus BXBY), d' context = hit rate (AX) - false alarm rate (BX) [both rates z-transformed], A-cue bias = -0.5*(hit rate (AX) + false alarm rate (BX)) [both rates z-transformed]. NEO aE = NEO agentic extraversion, NEO E = NEO extraversion.

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Neither task showed associations with (agentic) extraversion. In an additional correlational analysis we computed alternative indices of task performance (3-back task: d' prime, C; switching task: post-switch RTs per switching condition residualized from pre-switch RTs; AX-CPT: proactive index for RTs and error rates, Chiew & Braver, 2014). Except for a positive correlation between d' prime and fluid intelligence, we found no significant correlations among tasks or with (agentic) extraversion or fluid intelligence.

Discussion

We neither found the expected interactions between agentic extraversion and substance condition (and task condition) or the associations between agentic extraversion and task performance we had observed in previous studies (Herrmann & Wacker, 2021; Wacker, 2018; Wacker et al., 2006). As we did not find agentic extraversion to have effects on EF task performance, the question on potential task-specific versus shared effects could not be examined. Also, our correlational analyses did not reveal associations among the tasks beyond individual differences in general response latencies, although at least low to moderate correlations would have been expectable based on previous research on the relationship among EF tasks (Friedman & Miyake, 2017). This pattern was not changed by the use of alternative performance indices based on signal detection theory, or by residualized RTs instead of difference scores. When including fluid intelligence as a covariate into the analyses, it significantly explained task performance in all tasks across substance conditions. Nonetheless, accounting for shared variance with fluid intelligence did not change the general pattern of results, which speaks against the possibility that potential effects of agentic extraversion and substance condition were masked by effects of fluid intelligence. Furthermore, openness as another variable potentially associated with DA functioning (DeYoung, 2013; Käckenmester et al., 2019), did not explain task performance or masked the hypothesized effects, and neither did any other NEO scale.

The current study was designed to be similar to previous studies regarding the dosage of sulpiride, tasks used, and the healthy, similarly-aged sample, but differed regarding participant sex (only females in Wacker, 2018, and Herrmann & Wacker, 2021; only males here), sample size (N = 200 in the current study; N = 91 in Wacker, 2018; N = 82 in Herrmann & Wacker, 2021), timing of tasks relative to the beginning of the session (and sulpiride intake), usage of a different intelligence test, testing in groups of 3–4 participants rather than in individual sessions, number of demanding EF tasks, and an AX-CPT version without a preceding affect manipulation (as in Wacker, 2018).

Due to males' higher average body weight compared to females, the relative dosage of sulpiride is somewhat lower in the current study and may have resulted in lower serum levels. Serum levels might have further been affected by sex-differences in drug metabolization, potentially leading to less pronounced drug effects. However, preregistered studies on other parts of this dataset found significant effects of sulpiride on two

other tasks (Käckenmester et al., 2019; Ohmann et al., 2020), which were administered before and after the tasks of the current study. The effects of a low sulpiride dosage have been investigated several times, demonstrating that it produces striatal DA D2 receptor occupancy (Mehta et al., 2008) and also alters cognitive performance (Chavanon et al., 2007; Mehta et al., 1999). It therefore seems unlikely that the current dosage did not affect striatal DA during task completion. We opted for sufficient statistical power to detect at least small to medium effects. Because sulpiride produced effects on other tasks in the current dataset, and on EF tasks in the other just mentioned studies (which had less than 25% of our sample size), it further seems unlikely that our current study was underpowered. We therefore cannot rule out the possibility that the effects of interest are smaller than suggested by previous work. We decided against a higher sulpiride dosage, because it would have impeded comparability with previous studies without data on serum levels, and carries the risk that the overbalance of sulpiride's binding to presysnaptic DA autoreceptors versus postsynaptic DA receptors might be overturned, which would lead to DA-decreasing (instead of DA-increasing) effects (Mauri et al., 1996).

The different intelligence test and larger number of EF tasks may have affected performance, because compared to previous studies (Herrmann & Wacker, 2021; Wacker, 2018; Wacker et al., 2006), participants in the current study had slightly longer mean RTs per condition (up to 100 ms, > 0.5 *SD;* except for 3-back), while error rates were similarly low. Although we deem it unlikely that this caused the complete absence of the expected effects, we cannot rule out that the current study induced, for example, higher levels of cognitive fatigue or stronger discounting of mental effort. The extent of these confounding effects might further vary between individuals depending on other factors connected to extraversion, for example positive affect or reward sensitivity (Hermes et al., 2011; Wacker & Smillie, 2015). Also, whether and how the presence of other participants during the testing influenced performance, potentially also with differential extraversion-related effects, is unknown. However, as a previous study on the AX-CPT demonstrated that the effect of interest was present across affective conditions (Wacker, 2018), it seems at least unlikely that affective conditions influence its presence or absence.

The low reliability of difference scores from the switching task and the AX-CPT, computed to capture stability-flexibility, represents another limitation. The low reliability of EF tasks has been identified as a problem in research on the structure of EFs for quite some time (Friedman & Miyake, 2017). In our case the problem arises when we compute the difference between RT scores from different task conditions because these scores are highly correlated but at the same time not perfectly reliable (Trafimow, 2015). However, although task conditions in the switching task and AX-CPT elicited within-subject effects similar to previous studies, the tasks might generally not elicit sufficient interindividual variation in these within-subjects effects for correlational analyses.

Moreover, an alternative statistical approach with latent variable modeling (e.g. SEM) to ameliorate some of the current reliability issues does not seem to be a promising solution for our data due to the low correlations among the task performance measures. Obviously this limits the conclusions to be drawn from the current null-findings regarding extraversion-EF associations observed with these tasks. More generally, their low reliability argues against the further use of the switching task and AX-CPT for individual differences research, especially because a direct comparison with other EF tasks employed in individual differences research is yet to be conducted (e.g. keep track task, category switch task; Friedman & Miyake, 2017). Instead, we would suggest to make use of more reliable tasks specifically designed to measure individual differences in task performance (instead of within-subject effects similar for all individuals). Associations between individual differences in EFs and third variables, such as extraversion, could then either be analyzed with several tasks in a latent variable approach, or within a single task and an approach not in need of summary indices, such as drift diffusion modeling (Schmitz & Voss, 2012).

Compared to the quite stable associations between extraversion and positive affect (Hermes et al., 2011), as well as reward processing (Wacker & Smillie, 2015), associations between extraversion and EFs seem to be more nuanced and potentially smaller. Reliable tasks and a detailed understanding of EFs, and the differential effects dopaminergic drugs can have on them, are necessary to investigate a potential dopaminergic overlap with extraversion. Much effort in the last years has been spent to gain a better understanding of the interplay between prefrontal and striatal DA, and the effects of dopaminergic drugs on this interplay (Cools, 2019). We are optimistic that personality research can profit from these endeavors.

Conclusion

In sum, in this preregistered study we failed to replicate previous observations of an association between agentic extraversion and EF tasks, and their modulation by a pharmacological manipulation of DA using sulpiride (200 mg). Although we achieved higher statistical power in the current study compared to our own previous work, it is still insufficient to rule out small effects. Also, unexpected psychometric weaknesses of two of the three tasks (switching task and AX-CPT) limit conclusions to be drawn from our correlational analyses and speak against the future use of difference scores for these tasks in individual differences research. More preregistered research with large samples and psychometrically superior behavioral measures is needed to clarify the association between extraversion and EFs and its sensitivity to DA.

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Ethics Statement: The study was approved by the Human Research Ethics Committee of the German Society for Psychology.

Related Versions: The current analysis (https://osf.io/eazuh) and a list of all measures (https://osf.io/phr4g) were preregistered on August 9, 2017 after collecting 70 out of 200 datasets and before accessing any of the data. Data and analysis scripts are available under https://doi.org/10.7802/2374. Preregistered analyses on other parts of the dataset have been published by Ohmann et al. (2020), Käckenmester et al. (2019), and Smillie et al. (2021; Experiment 2).

Data Availability: For this article, data is freely available (for access see Index of Supplementary Materials below).

Supplementary Materials

For this article, the following Supplementary Materials are available (for access see Index of Supplementary Materials below):

- Pre-registration of the full project, linking to all specific pre-registrations
- Pre-registration of the current project
- Raw datasets for the three tasks and the NEO-PI-3
- Analysis dataset with clean, aggregated data
- Codebooks for raw datasets and analysis dataset
- R markdown code for preliminary analyses
- R markdown code for main analyses
- docx output from R markdown code for preliminary analyses
- docx output from R markdown code for main analyses

Index of Supplementary Materials

Herrmann, W., & Wacker, J. (2022). *Open data and analysis: Executive functions neither associated with agentic extraversion nor sensitive to the dopamine D2 blocker sulpiride* [Data, codebook, code, additional outputs]. Datorium. https://doi.org/10.7802/2374

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