Shared Dopaminergic Mechanisms Behind Extraversion and Executive Functions: An Experimental Approach

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Some things need to be experienced directly to fully grasp their meaning and implications. When I started my PhD, I was probably too naïve to understand why some people would say this journey was a marathon. Now I see why, but similar to many people before me, I will probably fail to make others understand what this journey meant to me, and to make other people truly see the role they played in this journey of mine. I will attempt it nonetheless!

First and foremost, I would like to thank my supervisor Prof. Dr. Jan Wacker. It took me quite some time to truly understand what it means to analyze and interpret results with caution. Thank you for giving me the freedom to make my own mistakes (which I am sure were plenty), and to learn from them by my own experience. Your patience with me, your stance on open science and good scientific practice, as well as your flexible, encouraging support throughout the years shaped me to become the researcher I am today.

I don’t know why, but my friends and family did not seem to grow tired of having to listen to endless hours of alternating enthusiasm and frustration, just because they dared to ask how my PhD was going. I am grateful for your encouragement as well as all the fun times we had when I wanted to think about something else (or nothing at all). Thank you, Ana, for our challenging self-reflective conversations, which increased my self-knowledge substantially and turned out to become a pillar of my mental health. Josie, I appreciated always having you nearby to readily participate in passionate rants about data analysis, and for emergency help when I looked at my R code for so long that it completely lost its meaning. Felix, your faith in my capability and your perseverance in reminding me of it were of immeasurable value to me. You were equally important in listening to and talking about my projects, as well as distracting me from them.

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Publications

This cumulative dissertation is based on three studies, for which articles have been published, accepted for publication (in press) or are currently under consideration for publication in peer-reviewed journals.

Herrmann, W., & Wacker, J. (2021). The Selective Dopamine D2 Blocker Sulpiride Modulates the Relationship Between Agentic Extraversion and Executive Functions. *Cognitive, Affective, & Behavioral Neuroscience, 21(4),* 852-867. https://doi.org/10.3758/s13415-021-00887-9

Herrmann, W. & Wacker, J. (in press). Executive Functions Neither Associated with Agentic Extraversion nor Sensitive to the Dopamine D2 Blocker Sulpiride in a Preregistered Study. *Personality Science*.

Herrmann, W. & Wacker, J. Executive Functions are Associated with Trait (but not State) Extraversion. Under review at *European Journal of Personality*.

Abstract

Initial studies suggest that extraversion and executive functions (EFs), such as working memory updating and shifting, are associated because they partly share individual differences in the dopamine (DA) system. However, it yet remains open whether (1) initial findings are replicable, especially regarding the sensitivity of extraversion-EF associations towards pharmacological manipulations of the DA system, (2) these associations are specific to updating or shifting, or can be attributed to rather general executive processes needed for all EF tasks, and whether (3) extraversion and EFs also causally affect each other. The current project approached these questions in three studies by investigating how performance in several EF tasks is affected by a manipulation of either DA activation via a pharmacological manipulation (DA receptor blocker sulpiride vs. placebo; studies 1 and 2), or extraverted states via acting instructions during a group discussion (enacted extraversion vs. introversion vs. control; study 3). Results of study 1 (*N* = 92) were in line with our expectations, as we found the interaction between drug condition and extraversion to explain performance in two EF tasks (updating, shifting), and that task performance could be partly explained by shared performance variance among tasks. Study 2 had a design similar to study 1 with several methodological improvements including a second task targeting shifting, but could not replicate any of the previously found effects in a larger sample (*N* = 200). In study 3 however (*N* = 108), we unexpectedly found extraversion-EF associations (updating, shifting), although we only expected effects for the three conditions of experimentally manipulated extraverted states. Although (state) extraversion did not seem to have a causal effect on EFs, it affected the spontaneous eye-blink rate as a putative marker of striatal DA activation. Overall, the results are compatible with a role of DA in extraversion-EF associations in studies 1 (sensitive to sulpiride) and 3 (change in eye-blink rate). As results of study 1 were not replicable in study 2, and we found no indication of (state) extraversion causally affecting EFs in study 3, the results are mixed at best. Considering limitations such as low EF task reliability, implications of the present results as well as future directions are discussed.

1. Introduction

The question what personality is, and why people differ in their personality, has been asked for thousands of years. Earliest recordings can be found in documents of Greek philosophers, for example of Theophrastus who described character types, such as “The chatty man” (Jebb, 1870). After some attempts to explain certain types of personality with biological functions, such as bodily fluids as suggested by Hippokrates, research of the 20th century arrived at more nuanced approaches. Instead of types, personality started to be described with different traits, each describing a person’s position on a continuum of relatively stable patterns of behavior, motivation, emotion, and cognition (Wilt & Revelle, 2009). Among several suggested traits, one of the most prominent was based on observations that some people are more talkative, dominant, and bold than others, inspiring many theories on the origin the trait nowadays termed *extraversion*.

One of the first to develop scales to measure extraversion, in order to map people on an introversion-extraversion continuum similar to today’s understanding of the term, was Hans Eysenck (1959). He further developed a theory stating that extraverts have lower cortical excitability and thus lower arousal, leading them to enact several behaviors with the goal to increase arousal, for example by responding more and faster in performance tasks (Eysenck, 1967). A competing theory from Jeffrey Gray, the Reinforcement Sensitivity Theory, proposed three separate neural systems which underlie behavior and, most importantly, connected extraversion to sensitivity to reward (J. A. Gray, 1970). Partly built upon Gray’s theory, Depue and Collins (1999) developed the currently dominating theory on the biological basis of extraversion, which proposes that extraversion can be partly ascribed to individual differences in a behavioral facilitation system, which increases the salience of positive stimuli and thereby explains extraverts’ stronger reward reactivity. Importantly, this theory concentrates on functions of the neurotransmitter dopamine (DA), which is also involved in numerous other neural processes, such as movement control and several higher-level cognitive processes subsumed under the term “executive functions” (EFs; Lappin et al., 2009; Luciana et al., 1992). Strikingly, individual differences in the latter have also been connected to extraversion, for instance in studies reporting better cognitive task performance with higher extraversion (Lieberman & Rosenthal, 2001). The growing number of findings on extraversion-EF associations gave rise to the idea that extraversion and EFs might partly share a dopaminergic basis (Berse et al., 2014; J. R. Gray & Braver, 2002; Lieberman & Rosenthal, 2001; Wacker et al., 2006). For instance, Lieberman and Rosenthal (2001) proposed that extraverts possess more social skills than introverts because their higher "central executive efficiency", regulated by DA, allows them to better multitask and therefore better read social cues.

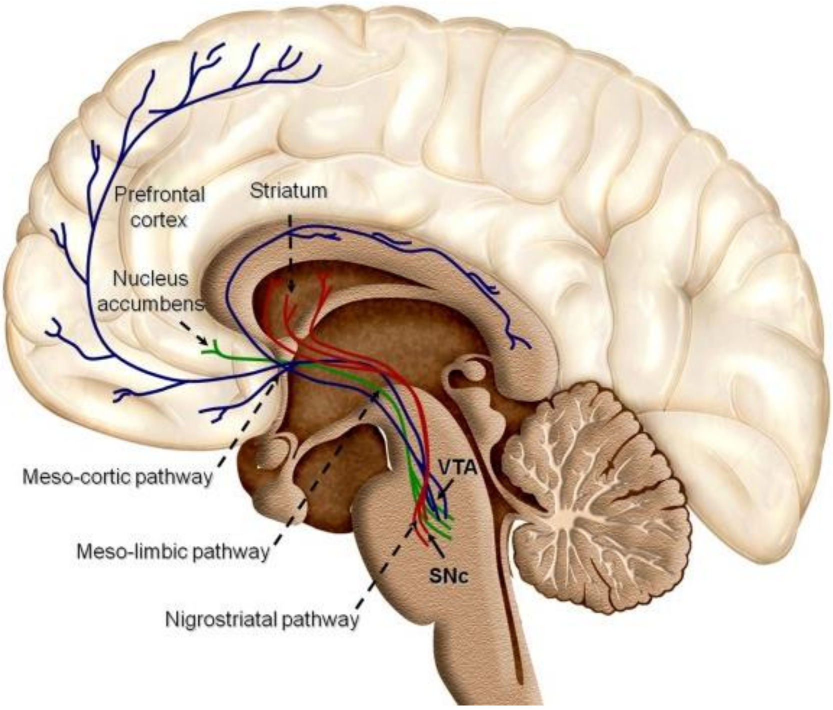
So far, evidence on extraversion-EF associations and their potential shared dopaminergic basis is limited. Previous findings are in need of replication, and further investigations are needed to understand which specific functions extraversion might be associated with. It further remains unclear whether extraversion and EFs also affect each other. The current project therefore aimed to investigate whether (1) previous findings of associations between extraversion and performance in tasks targeting different EFs are replicable, especially regarding the sensitivity of associations towards pharmacological manipulations of DA, (2) these associations can be ascribed to shared or function-specific EF processes, and (3) a manipulation of state extraversion has effects on EF task performance similar to associations with trait extraversion.

1.1 Extraversion

Extraversion is one factor of the commonly used five factor model of personality, which further comprises openness/intellect, conscientiousness, agreeableness and neuroticism (McCrae & Costa, 1987). The trait reflects variation in the tendency to be talkative, assertive and bold (Wilt & Revelle, 2009). Extraverts, i.e. individuals on the higher end of the trait extraversion continuum, are described as outgoing, sociable, cheerful individuals, who enjoy spending time with others, excel in leadership roles, and report high levels of positive affect and general life satisfaction (Costa & McCrae, 1980; Lucas et al., 2000; Lucas & Baird, 2004; Smillie, 2013). Introverts, i.e. individuals on the lower end of the continuum, are described as more quiet and reserved, rather staying in the background and enjoying activities in solitude (Smillie, 2013).

In the psychobiological theory of extraversion formulated by Depue and Collins (1999), which has been the prominent explanatory approach for the neural basis of extraversion for the past 20 years, extraversion is hypothesized to partly have a neural basis in the mesocorticolimbic DA system (Depue & Collins, 1999). Mesocorticolimbic DA pathways are assumed to regulate both reward anticipation and guiding of behavior to achieve rewards (Miller & Cohen, 2001). As depicted in Figure 1, they mostly originate in the ventral tegmental area and project to limbic and cortical regions, such as the nucleus accumbens in the ventral striatum and the amygdala (mesolimbic pathway), and the prefrontal cortex (mesocortical pathway; Depue & Collins, 1999; Smillie & Wacker, 2014). The theory suggests that higher tonic DA postsynaptic receptor activation leads to a lower threshold for behavioral facilitation in response to incentive stimuli, leading to an increase in several reward-

Figure 1. The Human Adult Mesocorticolimbic Dopamine System.



Note. Most human dopamine cells reside in the ventral tegmental area (VTA) and the substantia nigra pars compacta (SNc). The mesocorticolimbic dopamine system contains two partly overlapping pathways which project to the nucleus accumbens (mesolimbic pathway) and prefrontal cortical areas (mesocortical pathway). From "Dopaminergic reward system: a short integrative review" by O. Arias-Carrión et al., 2010, *International Archives of Medicine, 3: 24*. Copyright 2010 Arias-Carrión et al., reprinted with permission.

related mechanisms, such as an increased ascription of motivational salience and a higher reward sensitivity (Depue & Collins, 1999). Individual differences in this mechanism are hypothesized to be the basis for trait extraversion because they can parsimoniously explain its major components (Wacker & Smillie, 2015), especially those of the agentic component of extraversion including assertiveness, activity and a sense of accomplishing goals (Depue & Collins, 1999; Wacker, 2018).

On a behavioral level, there is evidence for associations between extraversion and mechanisms associated with higher DA activation. For instance, extraversion is positively associated with stronger reward reactivity/sensitivity and higher approach motivation (Blain et al., 2021; Robinson et al., 2010; Wacker et al., 2013). Extraversion has further been connected to performance in EF tasks, for which DA plays a crucial role (Cools, 2019). Several studies report associations between extraversion and EFs in tasks targeting working memory updating, set shifting and cognitive flexibility (Berse et al., 2014; Campbell et al., 2011; J. R. Gray & Braver, 2002; Lieberman & Rosenthal, 2001; Murdock et al., 2013). On a neural level, the association between extraversion and DA has been investigated with various neural measures, concentrating on the demonstration of theory-consistent associations (Wacker & Smillie, 2015). More specifically, extraversion has been associated with measures for structural or neurophysiological differences in DA-rich neural areas, such as striatal DA receptor density (Baik et al., 2012), gray matter volume in the caudate and nucleus accumbens (Lai et al., 2019; Li et al., 2019), cerebral perfusion in the basal ganglia (O'Gorman et al., 2006) or resting state glucose metabolism in the right putamen (Kim et al., 2008).

Since the association of extraversion with DA-related neural measures and DA-related behavior has been demonstrated in several studies, there has been a call for future research to provide causal evidence and incorporate other neurobiological processes (Wacker & Smillie, 2015). Testing whether an association between extraversion and another variable (such as cognitive task performance or neurophysiological measures) can be altered by pharmacological manipulations of brain DA activation meets this demand by testing the causal involvement of DA. A growing number of studies has taken this approach, and reported DA-sensitive associations between extraversion and cognitive tasks as well as neurophysiological measures using the DA blocker sulpiride. Sulpiride predominantly acts as a selective DA D2 antagonist binding on pre- and postsynaptic receptors in the striatum, with low dosages (up to 300 mg) increasing DA due to a relative overbalance of its binding to presynaptic autoreceptors, and higher dosages decreasing DA due to the relative overbalance of binding to postsynaptic receptors (Kuroki et al., 1999; Mauri et al., 1996). Using low dosages of 200 mg, sulpiride affected associations of extraversion with performance in a working memory updating task (Wacker et al., 2006), with performance in a cognitive flexibility task (Wacker, 2018), and with electroencephalogram indices for failure processing (prediction errors) in incentive contexts (Mueller, Burgdorf, Chavanon, Schweiger, Hennig, et al., 2014; Mueller, Burgdorf, Chavanon, Schweiger, Wacker, & Stemmler, 2014). These first results need to be replicated and checked for generalizability across different measures, because the total number of studies is relatively low and the applied tasks come with several methodological difficulties. The current project focuses on the relationship between extraversion and DA-related behavioral measures targeting EFs.

1.2 Executive Functions

EFs are defined as a set of high-level domain-general cognitive processes which help to regulate thoughts and actions during goal-directed behavior by influencing lower-level processes (Friedman & Miyake, 2017). EFs are closely related to the concept of *cognitive control*, which describes a set of mechanisms for pursuing relevant goals while suppressing distractions and no longer relevant goals, with the key functions to maintain, stabilize, and focus on current goal representations (Cools, 2016). There is yet no consensus on how these concepts relate to one another. EFs are sometimes viewed as a broader construct which additionally implicates long-term goal representation (Gratton et al., 2018), but are mostly used interchangeably with the term cognitive control (Diamond, 2013). The current work will mostly refer to the term *EFs*, which seems to be the more commonly used term in behavioral research on high-level cognitive processes and structure (e.g. Friedman & Miyake, 2017), but will occasionally use the term *cognitive control* as this term seems to be more common in cognitive neuroscience research on these processes (e.g. Cools et al., 2019).

Several processes have been described under the term EF, entailing shared and specific variance termed as “unity” and “diversity”, respectively. In other words, each EF task is assumed to tap several cognitive processes, of which some are recruited for all tasks, and some are particular to one family of tasks (Friedman et al., 2018). Within this unity-diversity framework, the total number of EFs depends on the level of analysis complexity in the frequently used latent variable analyses (Friedman & Miyake, 2017). Certainly most often, EFs are viewed on an intermediate level of complexity, which dissociates three families of processes around (1) the deliberate inhibition or overriding of dominant/prepotent responses (“EF inhibition”), (2) the updating of working memory representations (“EF updating”), and (3) the shifting of attention between goals, tasks, or task-sets (“EF shifting”; Miyake et al., 2000; Miyake & Friedman, 2012).

The current project focuses on the two EFs updating and shifting because, as mentioned previously, extraversion-related individual differences have been found for both of them. Both EFs yet need to be clearly distinguished from conceptually similar processes and their definitions should not be viewed as set in stone, because although there is a large body of research on each of these EFs and their unity-diversity, a consensus on their exact definition and the subprocesses they entail is yet to be found (Miyake & Friedman, 2012). For instance, it has been discussed that the structure of EFs might be better represented if EF inhibition was not included as a specific EF, but that it can be fully represented by shared variance among all EF tasks, labelled as “Common-EF” (for a meta-analysis see Karr et al., 2018). The following descriptions of the EFs updating and shifting therefore represent current well-established perspectives, but not universal definitions.

EF updating can be understood as an umbrella term for several operations with working memory representations, such as monitoring, retrieval, transformation, and substitution (Ecker et al., 2010; Miyake & Friedman, 2012). While the core process of updating tasks is to selectively replace, or disengage from, outdated information (Ecker et al., 2014), they necessarily require participants to also maintain relevant information, because otherwise there could be no *selective* updating. Since task performance is therefore not only reflected by individual differences in updating ability, but also by the ability to maintain information, updating tasks are also valid measures of working memory capacity (Frischkorn et al., 2022; Schmiedek et al., 2009). The n-back task is an often used task both in the context of EF updating and working memory capacity, because it requires a consecutive buffering (i.e. first maintaining, then updating) of continuously changing information (Miyake et al., 2000; Smith & Jonides, 1997).

Selectively maintaining and updating information seems to be relevant for both EFs updating and shifting, while the EFs differ in the abstraction level of information they operate on (Cools, 2019). Updating tasks operate on chunks of information with the goal to maintain and update them in a complex and demanding process (e.g. consecutively remember the last three numbers shown), whereas shifting tasks operate on more abstract (but rather easy) task-sets or goals which are maintained until updated via instruction (e.g. identify green numbers as odd/even while ignoring red numbers, until instructed to switch to identifying red numbers as odd/even). Shifting is often synonymously used with the term “switching” and can further be understood as a process-oriented term under the more general concept of cognitive flexibility, which describes a state of ease when engaging in shifting. As the counterpart of active maintenance and shielding of current goals or task-sets, it opposes cognitive stability (Cools & D’Esposito, 2011; Dreisbach & Fröber, 2019; Monsell, 2003). While stability prevents interference from distractors, it can also involve overly rigid, perseverative behavior and increase the risk to miss important information (Dreisbach & Fröber, 2019). Flexibility, as the consequence of reduced goal maintenance and shielding, can on the other hand increase distractibility (Dreisbach & Fröber, 2019). Individuals adaptively change from states of stability to flexibility and vice versa in response to environmental demands, forming a “stability-flexibility balance” (Dreisbach, 2006; Jongkees & Colzato, 2016).

To illustrate this, let’s imagine a person working in an office: Working in an environment with several things to attract attention, that person would have to be in a rather *stable state* in order to not be distracted by background chatter of their colleagues while concentrating on their work. At the same time, the person should still be aware of important things in their surroundings. They should notice when the fire alarm sets off, or perhaps even more important, when a colleague brings cake to the office. Once their office day is over, that person might want to stroll around in a supermarket to get inspired what to cook for dinner. A more *flexible state* would be adaptive for this activity to allow for exploration of their environment, but would also increase the chance to get distracted by in-store speaker announcements. In conclusion, there is no generally optimal way in stability-flexibility, but this balance needs to be adaptively regulated in a context-sensitive manner (Dreisbach & Fröber, 2019).

Apart from the unity-diversity of EFs, the fact that EF tasks operate by definition on lower-level processes poses the additional problem of "task impurity". For instance, shifting and updating tasks can operate on several processes, such as identification of numbers, letters, shapes, positions or more abstract concepts (e.g. living vs. non-living; cf. Friedman et al., 2008). Individual differences in task performance could therefore not only be due to the unity or diversity of the targeted EFs, but potentially also due to individual differences in lower-level processes. This "task impurity" adds error variance to the measurement of EFs, which is why EFs are often measured with several tasks operating on different lower-level processes, and analyzed with latent variable approaches in order to extract shared task variance (Miyake & Friedman, 2012).

On a neural level, all EF tasks activate the frontoparietal control network because they all require high-level processing (Reineberg et al., 2018). Some regions with modular, more specialized functions are only activated for specific EFs, such as lateral regions of the prefrontal cortex (PFC) for shifting attention towards a new goal (Lemire-Rodger et al., 2019). The striatum is assumed to play a central role for EFs: According to the "prefrontal-cortex basal-ganglia working-memory" model (PBWM; Frank & O'Reilly, 2006) it regulates selective updating of working memory representations in the PFC via a gating function within the corticostriatal loop (Chiew & Braver, 2017; Doll & Frank, 2009). Within this loop, DA activations in the PFC and striatum create a dynamic balance to regulate the selective maintenance versus updating of working memory representations (Cools & D'Esposito, 2011). A relatively higher activation in the striatum lowers the threshold for updating via phasic DA release, while a relatively higher activation in the PFC regulates maintenance via tonic DA release (Cools, 2016; Yee & Braver, 2018). As cognitive tasks require different levels of selective updating versus maintenance for optimal performance, optimal DA levels can vary between tasks (and accordingly, in all other contexts; Cools & D'Esposito, 2011). This model can therefore also explain why individual differences in striatal baseline DA are associated with task performance: Some individuals might have DA levels which are closer to the optimal DA level for a certain task than other individuals, leading to a performance advantage (Cools & D'Esposito, 2011).

1.3 Shared Mechanisms Behind Extraversion and Executive Functions

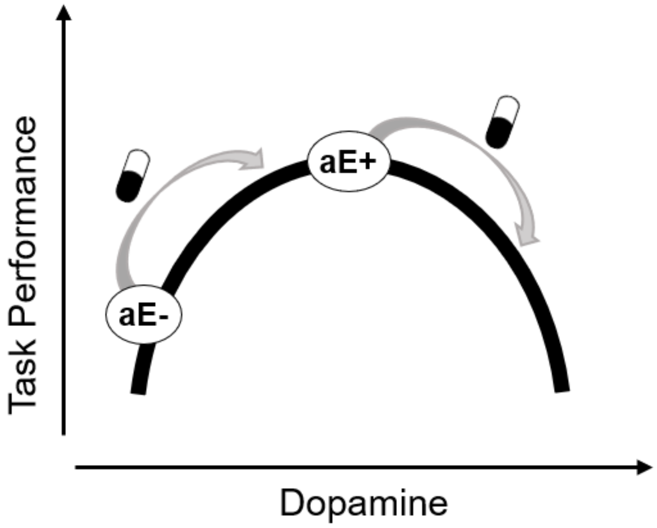
While there is growing evidence for a behavioral relationship between extraversion and EFs, it is yet unclear which cognitive and/or neural mechanisms stand behind it. From a rather cognitive-behavioral perspective, certain features of extraversion could influence EFs, for instance extraversion-related motivational differences could affect task performance by affecting the willingness to exert cognitive effort (cf. Westbrook et al., 2021). Reversely, individual differences in EFs could enable individuals to better carry out certain social behaviors, for instance to better multitask in group conversations, and therefore provide the skills to act in a more extraverted way (Lieberman & Rosenthal, 2001). Another explanation from a rather neural perspective involves a shared neural mechanism which might partly regulate both trait extraversion and EFs, without extraversion and EFs directly affecting each other (Herrmann & Wacker, 2021).

This shared neural dimension has been suggested to be located in the striatum (Berse et al., 2014; Wacker, 2018), as striatal DA pathways have been found to partly regulate stability-flexibility (Cools, 2019), and extraversion has likewise been associated with individual differences in dopaminergic pathways involving the striatum both theoretically (Depue & Collins, 1999) and empirically (Baik et al., 2012; Lai et al., 2019; Wacker & Smillie, 2015). A shared striatal mechanism could, for instance, regulate the updating threshold for working memory and/or goal representations, leading to (1) variation in updating/higher flexibility, and (2) variation in multitasking in group conversations, reflected as variation in trait extraversion. Alternatively, a shared striatal mechanism could regulate the threshold for behavioral facilitation in incentive contexts, leading to (1) variation in reward sensitivity, reflected as variation in extraversion, and (2) variation in cognitive effort discounting by biasing cost-benefit decisions, reflected as variation in cognitive effort investment in EF tasks. However, before any of these speculations on the function of a potential shared mechanism can be investigated, associations between extraversion and EF task performance and their dopaminergic basis need to be further established.

The earlier mentioned approach of using dopaminergic drugs, such as sulpiride, to investigate whether extraversion-EF associations are DA-sensitive shows an interesting parallel regarding the drugs' effects with studies on the neural mechanisms behind EFs. The effects of dopaminergic drugs have been shown to be baseline-dependent, meaning that several pharmacological studies found these drugs to affect EF task performance differently depending on baseline striatal DA synthesis capacity and baseline cognitive performance (Cools, 2019; Fallon et al., 2019; Westbrook et al., 2021). As mentioned before, the same drugs have been found to affect task performance differently depending on (agentic) extraversion (Wacker et al., 2006; Wacker, 2018). Both lines of research attribute these differential drug effects to models describing an inverted-U shaped relationship between DA levels and EF task performance (Figure 2), in which both too low and too high DA levels can impair performance (Cools & Robbins, 2004). Accordingly, dopaminergic drugs can affect an individual's baseline task performance differently by bringing their baseline DA levels closer to, or further away from, the optimum (Cools & D'Esposito, 2011). From this line of reasoning follows that if factors, such as baseline EF task performance or trait (agentic) extraversion, can explain whether a drug improves or impairs performance similarly to baseline striatal DA synthesis capacity, they should be somewhat associated with baseline DA levels (see white circles in Figure 2).

Although empirical findings on DA-sensitive extraversion-EF associations are suggestive of a partly shared dopaminergic mechanism, they leave open several questions and underline the need for replication and closer investigation. Firstly, several problems arise with the measurement of EFs due to their unity-diversity and task impurity. By investigating extraversion-dependent effects of dopaminergic drugs with only one EF task, previous studies did not have the opportunity to consider shared task variance, indicating unity and/or task impurity, and may therefore have overestimated the specifity of effects (Karr et al., 2018). Secondly, effects in psychological studies without preregistration have been shown to be larger, while sample sizes are smaller, than in preregistered studies, indicating that several previously published effects may have been overestimated and studies underpowered (Schäfer & Schwarz, 2019). While this must not necessarily be the case for

Figure 2. Inverted-U shape Model on the Relationship Between Dopamine and Performance in Executive Functioning Tasks.



Note. The model depicts the relationship between baseline dopamine and performance in executive functioning tasks with white circles depicting the presumed position on the curve for individuals low (aE-) and high (aE+) in agentic extraversion (aE). The arrows illustrate how the association between agentic extraversion and task performance could be altered under a DA-increasing pharmacological manipulation, such as a low dosage of sulpiride.

effects reported on extraversion-EF associations, higher-powered preregistered studies are helpful to clarify this. Thirdly, previous findings have indicated extraversion-EF relationships in different directions, reporting the relationship with stability-flexibility to be either negative (Wacker, 2018), positive (Berse et al., 2014), or found no indication for a relationship (Murdock et al., 2013; Vaughan & Edwards, 2020). Further studies are needed to investigate whether these associations indicate false-positive findings around an actual null effect or whether, for example, systematic variation of potential moderators affected the direction of effects.

1.4 The Role of Positive Affective-Motivational States

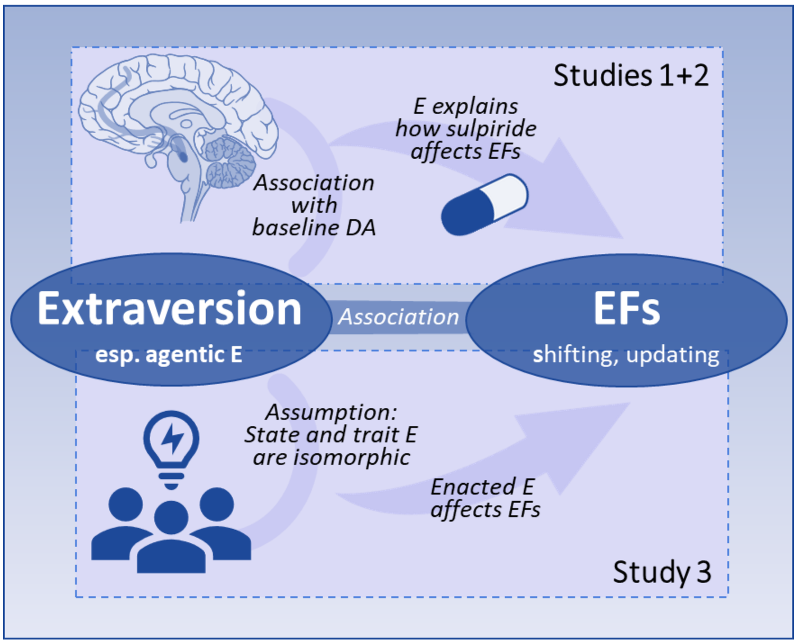
Positive affective-motivational states might influence extraversion-EF relationships because states of this spectrum have been strongly connected to both extraversion and EFs separately. The term "positive affective-motivational states" is here used to describe variation in states of positive affect (PA) and approach motivation, both jointly and independently. As mentioned before, extraversion is robustly related to PA, which has been demonstrated for different cultures (Fulmer et al., 2010; Schimmack et al., 2002) and remains a stable finding when conceptual or methodological overlaps are removed (e.g. extraversion items referring to affective content, or the two concepts measured with self-report questionnaires; Lucas & Fujita, 2000; Smillie, DeYoung, & Hall, 2015). The relation between E and PA is not only visible between individuals, but also within: PA increases when individuals act more extraverted, mostly irrespective of whether this behavior is shown naturally, after an acting instruction, in everyday life or in the lab (Fleeson et al., 2002; Jacques-Hamilton et al., 2018; Smillie, 2013; van Allen et al., 2021). Extraversion is also strongly connected to approach motivation, as a higher likelihood to be in approach-motivated states is an integral feature of extraverts (due to their theoretically lower threshold for behavioral facilitation in incentive contexts; Depue & Collins, 1999), and is reflected in behavioral and questionnaire indices of reward sensitivity, as well as in neural markers of reward processing (Blain et al., 2021; Cooper et al., 2014; Corr & Cooper, 2016; Depue & Fu, 2013; Neo et al., 2021; Smillie et al., 2011; Smillie et al., 2019).

Positive affective-motivational states also play an important role for the regulation of EFs, especially for the adaptive regulation of stability-flexibility (for reviews see Paul et al., 2021; Dreisbach & Fröber, 2019). There is an ample amount of evidence for the hypothesis that positive affective-motivational states act as indicators for environmental demands the individual constantly needs to adapt to, for instance when an incentive is present or when the environment allows for exploration (Dreisbach & Fröber, 2019). High PA in combination with a *low* approach motivation has been found to increase cognitive flexibility and widen the attentional scope. This response is theorized to be adaptive because low approach-motivated, hence relaxed, positive states could indicate an environment which allows for exploration and in which cognitive resources can be saved (Paul et al., 2021). As opposed to this, high PA in combination with *high* approach motivation has been found to increase cognitive stability and to narrow the attentional scope, which is theorized to be an adaptive response in the context of an incentive, e.g. a reward, to enable focused, goal-directed action. Importantly, not all incentives induce high approach motivation: They need to be performance-contingent, i.e. their receipt must depend on behavior/performance, which seems logical as otherwise a high approach motivation to obtain them would not be adaptive (Fröber & Dreisbach, 2014).

While the role of positive affective-motivational states for the regulation of stability-flexibility is quite established, there seem to be less findings regarding their role for performance in EF updating tasks. Some studies report that PA increases performance in working memory tasks, both after affective manipulations in the lab, or when measured in everyday life (Brose et al., 2014; Carpenter et al., 2013; Figueira et al., 2018; Storbeck et al., 2018; Yang et al., 2013). However, it yet seems to remain unclear whether variation in motivational states also has effects (cf. J. R. Gray, 2001), and whether previous results affected working memory *updating* or *capacity*. As EFs share a substantial amount of variance, a joint analysis of tasks targeting both EFs within the same study might help to clarify state-EF relationships.

To summarize, a growing amount of research suggests that trait extraversion, especially its agentic component, and EFs are associated, and that this relationship might be ascribed to shared dopaminergic processes. However, previous studies are limited by several methodological factors. As reliability of measurements has not been routinely reported in previous studies, it is possible that measures were unreliable, potentially due to high error variance, which would decrease power and increase the likelihood for false positives (Parsons et al., 2019). Further limitations involve relatively small sample sizes, the use of only one task within each study, and only few investigations of state effects. Reasons may partly lie in the problem that latent variable approaches for the measurement of EFs can be rather resource-intense, because participants need to complete a significant number of different tasks (e.g. three per EF; Miyake et al., 2000). Investigating EF-trait associations with (at least) more than one task, and analyzing shared variance between tasks, can be an economically feasible starting point to learn about the specificity of potential associations. The current project

Figure 3. Graphic Summary of the Central Hypotheses of the Current Project



Note. By either manipulating central dopamine activation via sulpiride (studies 1 and 2), or state extraversion via trait enactments (study 3), we experimentally investigated previously reported associations between extraversion and executive functions. DA = dopamine; EFs = executive functions; E = extraversion.

implemented this approach in three studies to address previous limitations when investigating the relationship between extraversion and EFs, its potential specificity to certain EFs, as well as its potential dopaminergic basis. By either manipulating central DA activation or positive affective-motivational states, we further aimed to approach the question whether previously reported associations can be ascribed to causal mechanisms. Figure 3 presents a graphic summary of the central hypotheses of studies 1, 2 (upper half), and 3 (lower half).

2. The Present Research

The goals of the present project were to investigate whether extraversion is associated with performance in different EF tasks, whether these associations can be ascribed to shared or function-specific processes and whether EF task performance is sensitive to either a manipulation of central DA activation via sulpiride, or to a behavioral manipulation of state extraversion. DA activation (studies 1 and 2) or state extraversion (study 3) were manipulated to not only test whether a relationship exists, but also to gain first insight into potential causal mechanisms. For studies 1 and 2, we expected trait extraversion to explain individual differences in EF task performance. We further expected this effect to be sensitive to manipulations of DA activation. For study 3, we expected EF task performance to be influenced by an experimental manipulation of state extraversion.

2.1 Study 1: The Selective Dopamine D2 Blocker Sulpiride Modulates the Relationship Between Agentic Extraversion and Executive Functions

2.1.1 Background

The first study investigated DA-sensitive associations between extraversion and two tasks, which targeted EF updating and shifting. To measure EF updating, we selected a task for which a DA-sensitive association with extreme groups of extraverts and introverts has been demonstrated before (n-back task; Wacker et al., 2006). As for other EF updating tasks, extraversion-related individual differences in task performance were demonstrated to be more pronounced for more complex task versions (Campbell et al., 2011; Wacker et al., 2006), which is why we applied the 3-back task version. In this version, participants continuously indicate whether a currently presented stimulus, in this case a letter, is identical to the stimulus presented *three* trials before. To measure EF shifting, we selected the switching task (Müller, Dreisbach, Goschke, et al., 2007) for which a DA-sensitive association with extraversion seemed plausible due to previous evidence for its modulation by dopaminergic processes (Dreisbach et al., 2005; Müller, Dreisbach, Brocke, et al., 2007; Owen et al., 1993) and its sensitivity to alterations in PA and motivation (Dreisbach & Goschke, 2004; Müller, Dreisbach, Goschke, et al., 2007).

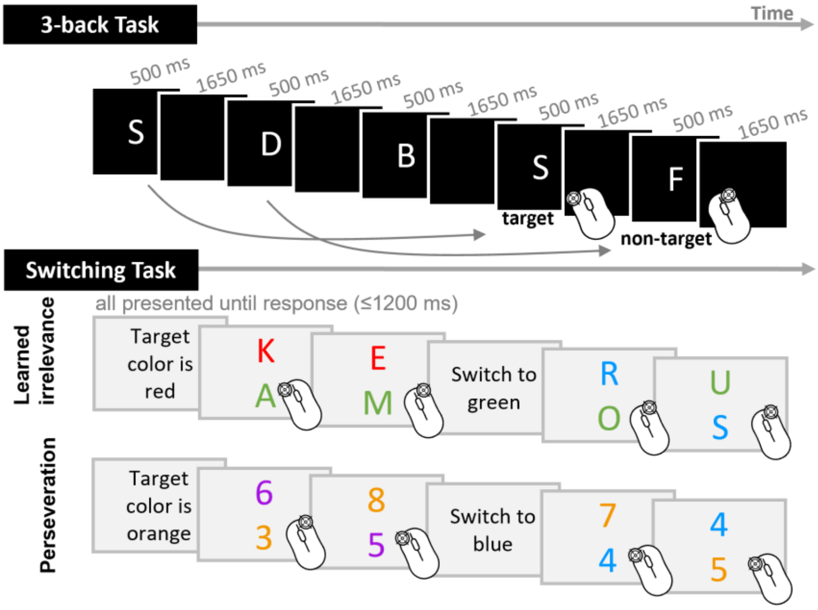
The first study was designed to test whether potential associations between extraversion and performance in these two tasks are sensitive to a pharmacological manipulation of brain DA with the DA D2 antagonist sulpiride. The aims of the study were to investigate whether (1) we could replicate the previously reported relationship between extraversion and 3-back performance, (2) we could find the presumed relationship between extraversion and switching performance, (3) both relationships are sensitive to a pharmacological manipulation of brain DA and (4) potential effects are task-specific or can rather be ascribed to shared functions behind both tasks. We expected to find relationships between extraversion and performance in both tasks for the control condition, and an alteration of these relationships for the sulpiride condition. As this was the first study to investigate the dopaminergic basis behind extraversion-EF relationships with more than one task, the question whether potential effects could rather be ascribed to task-specific or shared functions among the two tasks was open-ended.

2.1.2 Methods

In a double-blind between-subjects design, ninety-two healthy female participants were randomly assigned to orally consume a capsule of either 200 mg sulpiride or a nondistinguishable placebo. Participants first completed a test of fluid intelligence (CFT-3, Cattell & Weiß, 1971) during the time before sulpiride is expected to take effect (about one hour; Mauri et al., 1996). Afterwards, participants first completed the 3-back version of the n-back task (Wacker et al., 2006), and then the switching task (Müller, Dreisbach, Goschke, et al., 2007).

In the switching task, participants were informed about target- and distractor colors at the start and one “switch” (after 40 trials) per block, and then identified numbers or letters in the target-color as vowel/consonant or odd/even, while ignoring the stimulus in the distractor-color. We measured performance based on switch costs, defined as mean reaction times (RTs) of the five trials after minus five trials before the switch, for which we computed the difference between task conditions (learned irrelevance minus perseverance; Figure 4). Lower switch costs in the learned irrelevance condition are assumed to indicate higher *stability*, which should be advantageous to ignore the new (but irrelevant) color of the post-switch distractor. Lower switch costs in the perseverance condition are assumed to indicate higher *flexibility*, which should be advantageous to update the new (and relevant) color of the post-switch target, and to faster disengage from the pre-switch target color when it becomes the post-switch distractor. Higher values in the switch cost difference therefore indicate higher flexibility, and lower or even negative values indicate stability (cf. Dreisbach & Goschke, 2004). In the 3-back task, participants had to indicate whether a presented letter was identical to the letter three trials earlier (target trial) or not (non-target trial). The analysis focused on target trials, for which lower mean RTs and higher mean accuracy were used as measures for better updating ability. Figure 4 illustrates example trials of the tasks and their within-subject conditions. We included the factors condition (placebo vs. sulpiride), agentic extraversion, and their interaction into one regression model explaining multivariate task performance in order to consider variation in the three performance measures simultaneously.

Figure 4. Exampe Trials of Within-Subject Conditions of the Two EF Tasks.



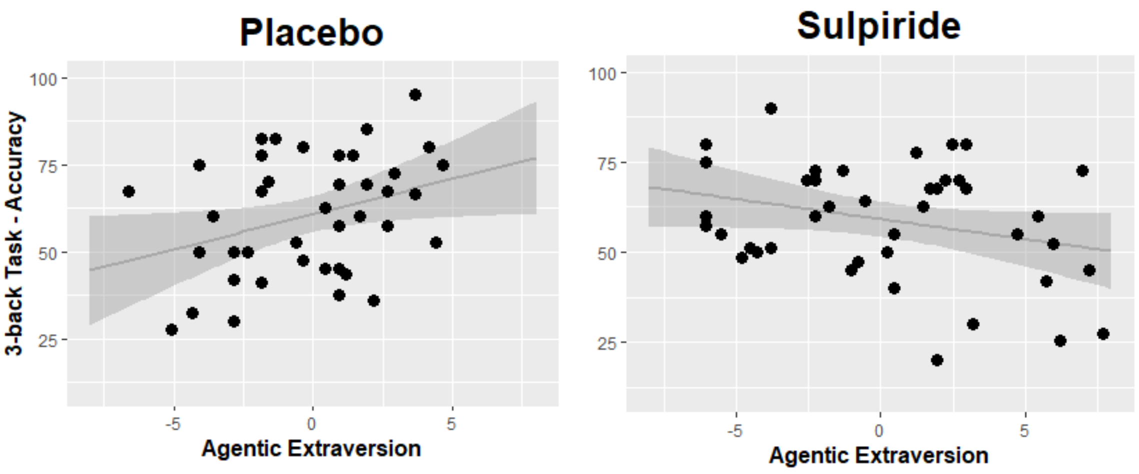
Note. Example trials of the two EF tasks with different within-subject conditions. Grey numbers refer to stimulus presentation times. Each mouse icon signifies the correct reaction for one trial (left or right click). **3-back task:** Letters in (non-)target trials are (not) identical to the letter three trials earlier (as indicated by grey arrows). **Switching Task:** Learned irrelevance: The previous distractor color becomes the new target color, a new color becomes the distractor color. Perseveration: A new color becomes the target color, the previous target color becomes the distractor color.

2.1.3 Results

Preliminary analyses revealed an unsatisfactory reliability of the switch cost difference among the three task-blocks per switching condition (Cronbach's α = .22). Split-half reliability of the 3-back task was excellent for 3-back target RTs (Rel. = .91) and good for 3-back target accuracy (Rel. = .83). The main analysis revealed a significant main effect for agentic extraversion (*F*(3, 76) = 4.53, *p* = .006) as well as its interaction with condition (*F*(3, 76) = 4.15, *p* = .009) on multivariate task performance. In follow-up univariate analyses, 3-back accuracy was significantly explained by both agentic extraversion (*F*(1, 78) = 5.06, *p* = .027) and its interaction with substance condition (*F*(1,78) = 8.32, *p* = .005), while there were no significant effects on 3-back RTs. The switch cost difference was also explained by both agentic extraversion (*F*(1, 78) = 5.40, *p* = .023) and its interaction with substance condition (*F*(1, 78) = 4.12, *p* = .046).

Effects on 3-back target accuracy and the switch cost difference were partly caused by shared variance among the tasks, indicated by the finding (1) that effects of condition and agentic extraversion were somewhat attenuated when the respective other task measures were added as

Figure 5. Scatterplots per Condition on the Relationship between Agentic Extraversion and Accuracy in the 3-back Task.



Note. Agentic extraversion is centered within condition. 3-back task accuracy (in %) refers to target trials only. The lines represent fitted linear regression lines with 95% confidence intervals.

covariates into each model on univariate task performance, and (2) that 3-back accuracy (*F*(1, 74) = 4.32, *p* = .041) and its interaction with condition (*F*(1, 74) = 7.72, *p* = .007) had significant effects on the switch cost difference, and reversely, the switch cost difference (*F*(1, 74) = 5.41, *p* = .023) and its interaction with condition (*F*(1, 74) = 8.72, *p* = .004) had significant effects on 3-back accuracy.

This pattern of shared variance was also visible in follow-up analyses of pairwise correlations within substance conditions, for which we found a positive relationship between agentic extraversion and 3-back accuracy in the placebo condition (*r*(38) = 0.33, *p* = 0.035), and a significantly different, negative relationship in the sulpiride condition (*r*(40) = −0.28, *p* = 0.068; difference: *z* = 2.71, *p* = 0.006; see Figure 5). Agentic extraversion further correlated positively with the switch cost difference in the placebo condition (*r*(38) = 0.38, *p* = 0.014), while there was no relationship in the sulpiride condition (*r*(38) = -.03, *p* = 0.861; difference: *z* = 1.84, *p* = 0.067). The relationship between 3-back target accuracy and the switch cost difference was positive in the placebo condition (*r*(38)= .44, *p* = .005), but tended to be negative in the sulpiride condition (r(40) = .26, p= .091; difference: *z* = 3.12, *p* = .002).

2.1.4 Discussion

This study was the first in the context of extraversion-EF associations to report reliability indices for the EF tasks applied. While the 3-back task showed good reliability, the switching task's reliability was unsatisfactory. A low reliability limits the power to find correlations with other measures (Parsons et al., 2019; Spearman, 1904), which in this case poses a fundamental problem for the investigation of potential associations with extraversion. Overall, the first study still supports previous findings on associations between trait (agentic) extraversion and EFs. As in a previous study, higher extraversion was associated with better 3-back performance, although this time the relationship was reflected in higher accuracy instead of faster RTs (cf. Wacker et al., 2006). The finding that agentic extraversion was associated with higher flexibility in the switching task stands in contrast to a previous study reporting agentic extraversion to be associated with higher stability, albeit in a different task (Wacker, 2018). The first study further supports previous findings regarding the sensitivity of these associations to a dopaminergic modulation.

The results provide the novel finding that associations between extraversion and different EFs are not completely independent from each other, but suggest that they can partly be ascribed to shared executive processes. This implies that previously reported associations between extraversion and performance in a single task might not be as specific as expected. Further studies are needed to confirm this finding, especially because results of the switching task are limited by its low reliability as well as its association with agentic extraversion in the opposite direction as in a previous study.

2.2 Study 2: Executive Functions Neither Associated with Agentic Extraversion nor Sensitive to the Dopamine D2 Blocker Sulpiride in a Preregistered Study

2.2.1 Background

The second study was conducted as part of a larger project on the dopaminergic foundations of personality, with the aim to build upon the findings of study 1 by conceptually replicating associations between trait extraversion and cognitive task performance. Several improvements in design and research practice were included, such as the addition of another cognitive task (AX-continuous performance task; AX-CPT; as in Wacker, 2018) as a second measure[1] of stability-flexibility, a considerably larger sample, this time consisting of male participants, and a preregistration of study design, hypotheses and analysis plan. As in study 1, we expected to find relationships between extraversion and performance in EF tasks for the control condition, and an alteration of these relationships for the sulpiride condition. We further expected the effects to be somewhat attenuated after accounting for shared variance in the respective other task measures.

2.2.2 Methods

We employed a double-blind between-subjects design with 200 healthy male participants who were randomly assigned to orally consume a capsule of either 200 mg sulpiride or a nondistinguishable placebo. We applied a different test of fluid intelligence (INSBAT; Arendasy et al., 2012), which was completed during the time before sulpiride is expected to take effect (about one hour; Mauri et al., 1996). After two other tasks not relevant to the current research question, participants completed the 3-back version of the n-back task, the switching task, and the AX-CPT. The 3-back and the switching task were identical to the tasks from the first study. In the AX-CPT, participants were continuously presented letters with the instruction to right-click whenever the cue A was followed by an X (70% of all trials), and left-click whenever the cue A was followed by a letter other than X, or when a cue other than A was presented (except when instructed otherwise in

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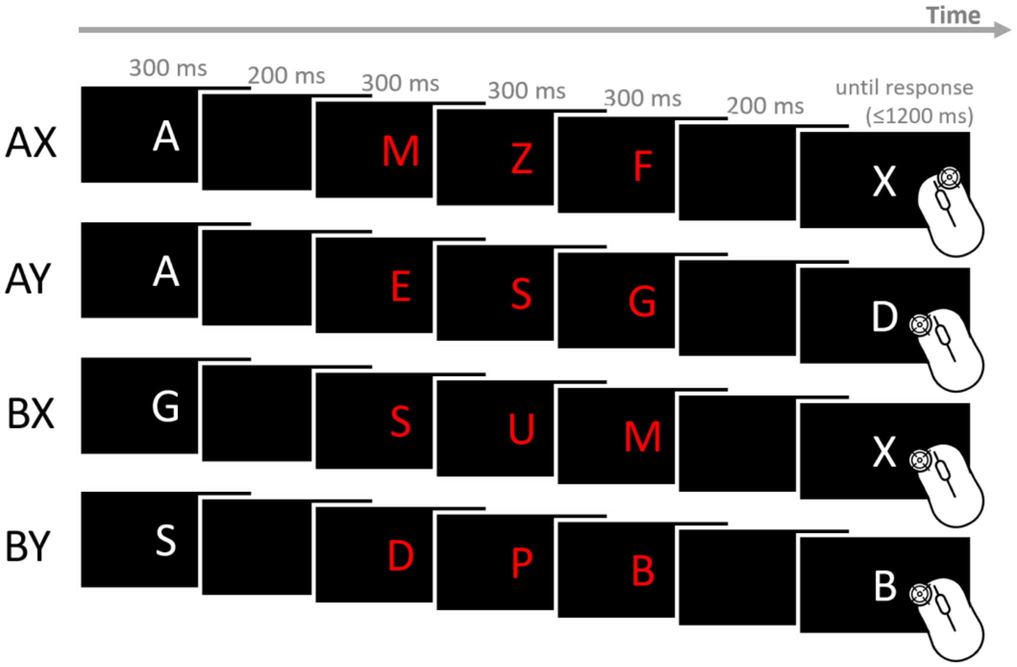
[1] The unexpectedly low reliability of the switching task's difference scores emerged after data collection of study 2 was finished and data collection of study 3 had already started, which is why the task design was not altered to improve reliability.

Figure 6. Exampe Trials of Within-Subject Conditions of the AX-CPT.



Note. Example trials of the AX-continuous performance task 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). 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.

“catch” trials). Example trials of the four within-subject conditions from the AX-CPT are illustrated in Figure 6. We measured performance as median RTs for correct trials in the within-subject conditions AY and the average of BX and BY trials (BXBY). Faster RTs in AY-trials are assumed to reflect flexibility, because the lower maintenance of the cue reduces the bias towards the most often presented AX-trials. Faster RTs in BXBY-trials are assumed to reflect stability, because higher maintenance of the cue B should allow for faster reactions.

Study 2 took a slightly different analysis approach by measuring task performance per within-subject condition (for the switching task and AX-CPT) and including within-condition effects in the analysis as an attempt to avoid the use of potentially unreliable difference scores and have a higher power in the analysis. We investigated effects of between-subject condition (placebo vs. sulpiride), within-subject conditions, agentic extraversion, and all interactions, on performance in the three tasks with multiple regression models.

2.2.3 Results

As in study 1, preliminary analyses revealed a low reliability for difference scores for the switching task (Cronbach's α < .27), as well as for the AX-CPT (Rel. = .52), while reliability of mean RTs from within-subject conditions was good for both tasks (Rel. > .81). The main analysis was performed with the more reliable performance measures per condition, for which the switching task and the AX-CPT showed the expected within-subject condition effects, indicating that the task conditions affected performance as intended. More specifically, RTs in the switching task were significantly lower over time (from block 1 to 6; *B* = -0.007, *p* < .001), and before the switches (versus after; *B* = -0.016, *p* <.001). RTs in the AX-CPT were expectedly faster in the BXBY condition compared to AY (*B* = 0.0575, *p* <.001).

Against expectations however, none of the tasks showed the hypothesized effects of substance condition and agentic extraversion in the highest-order interactions (partly including within-subject conditions, all *p*s > .593). We found only tendencies for effects in lower-order interactions which were not hypothesized, such as a significant substance condition main effect on 3-back accuracy (*B* = 2.749, *p* = .044), and in the switching task a significant interaction between substance condition and the contrast between pre- versus post-switch trials (*B* = -0.0034, *p* = .035). As we did not find the expected task effects, potential shared variance among task performance measures (as in study 1) was not analyzed. Potential effects were not masked by fluid intelligence, for which an additional analysis revealed main effects in all tasks, but no clear patterns of interactions with substance condition or extraversion. Including any other NEO trait as covariate did not reveal any effects. There further were no correlations between (agentic) extraversion and any task measure.

2.2.4 Discussion

Results of study 2 contradict the findings of study 1 and of previous research reporting a relationship between extraversion and EFs. Apart from the explanation that the hypothesized relationship between extraversion and EFs does not exist, several other explanations could potentially stand behind these unexpected results. The lack of a relationship between extraversion and EFs in the placebo condition might be explained by differences in the experimental time course and design of the current experiment compared to previous studies, for example in study length or task order. These differences could have impacted motivational factors of task performance differently in the current study compared to previous studies (cf. Westbrook et al., 2020), which might also have blurred potential effects of sulpiride. Assuming that trait-related individual differences are only visible if they are activated by a relevant situation (Stemmler, 1997), a tighter control of motivational effects might be especially relevant for the investigation of extraversion-related associations due to the conceptual proximity of extraversion and motivation. It is further unlikely but possible that we did not find sulpiride effects because it (rather generally) did not affect cognitive mechanisms. However, the current dose of 200 mg likely altered striatal DA activation as intended, because studies on other parts of the dataset revealed differences between the placebo and sulpiride condition in cognitive measures assessed before and after the currently analyzed tasks were administered (Käckenmester et al., 2019; Ohmann et al., 2020; Smillie et al., 2021). Lastly, the low reliability of the switching task and AX-CPT difference scores indicates that the tasks might have not produced enough variation between individuals in the processes of interest. This problem cannot be solved by analyzing the more reliable RT-based measures of both tasks and thus avoiding difference scores, because the higher between-subject variance in RT-based measures probably reflects individual differences in response latencies, and not in the targeted EF processes.

In summary, the second study presents a failed attempt to conceptually replicate the results of study 1, with several potential explanations which might stand behind the lack of effects. After the mixed findings of studies 1 and 2, we attempted to experimentally approach extraversion-EF associations from a different direction by behaviorally manipulating extraversion and investigating causal effects on EFs.

2.3 Study 3: Executive Functions are Associated with Trait (but not State) Extraversion

2.3.1 Background

Study 3 investigated the relationship between extraversion and EFs from a new perspective. While the first and second study tested whether a manipulation on a neurophysiological level affects the relationship between extraversion and EFs, the third study aimed to manipulate extraverted behavior in order to assess its potential causal effects on PA, EFs and on the spontaneous eye-blink rate (EBR) as a putative marker of striatal DA activation (Jongkees & Colzato, 2016). Several previous studies demonstrated positive affective consequences of enacted extraverted behavior, i.e. when participants are instructed to act bold, talkative, energetic, assertive, and adventurous (vs. reserved, quiet, lethargic, passive, compliant, and unadventurous; cf. Fleeson et al., 2002; Smillie, Wilt, et al., 2015; Zelenski et al., 2012). Extraverted behavior seems to have positive affective consequences irrespective of trait extraversion in the lab (Smillie, Wilt, et al., 2015; Sun et al., 2017) with findings sometimes depending on trait extraversion in experience-sampling studies (Jacques-Hamilton et al., 2018, but not van Allen et al., 2021 and Margolis & Lyubomirsky, 2020). These consequences are similar to those of naturally shown extraverted behavior and, based on the view of traits as density distributions of states (Fleeson & Jayawickreme, 2015, 2021), offer the opportunity to use state enactments as a means to better understand their associated traits. The above mentioned findings therefore sparked the idea that enacted extraversion (vs. introversion vs. uninstructed control) could not only be used to investigate affective, but also cognitive correlates of extraverted behavior with experimental methods.

The aim of study 3 was to investigate whether acting condition has effects (1) on state PA, (2) on EFs measured with two tasks, and (3) on the EBR as a putative marker of striatal DA activation in an exploratory analysis. We expected acting condition to have effects on state extraversion and state PA similar to previous studies using the enacted extraversion paradigm, and on EF task performance similar to effects suggested by previously reported trait extraversion-EF associations.

2.3.2 Methods

In this randomized controlled experiment, participants were tested in groups of three (total *N* = 108) with each participant per testing group being assigned to a different acting condition (enacted extraversion vs. enacted introversion vs. control). Participants engaged in two group discussion rounds, each followed by physiological, cognitive and self-report measures. Directly after each discussion, we exploratorily assessed the spontaneous eye-blink rate as a putative marker of striatal DA activation, followed by an EF task (switching or 3-back task as in studies 1 and 2; randomized between groups), and questionnaires of state extraversion and PA in self- and/or informant-ratings.

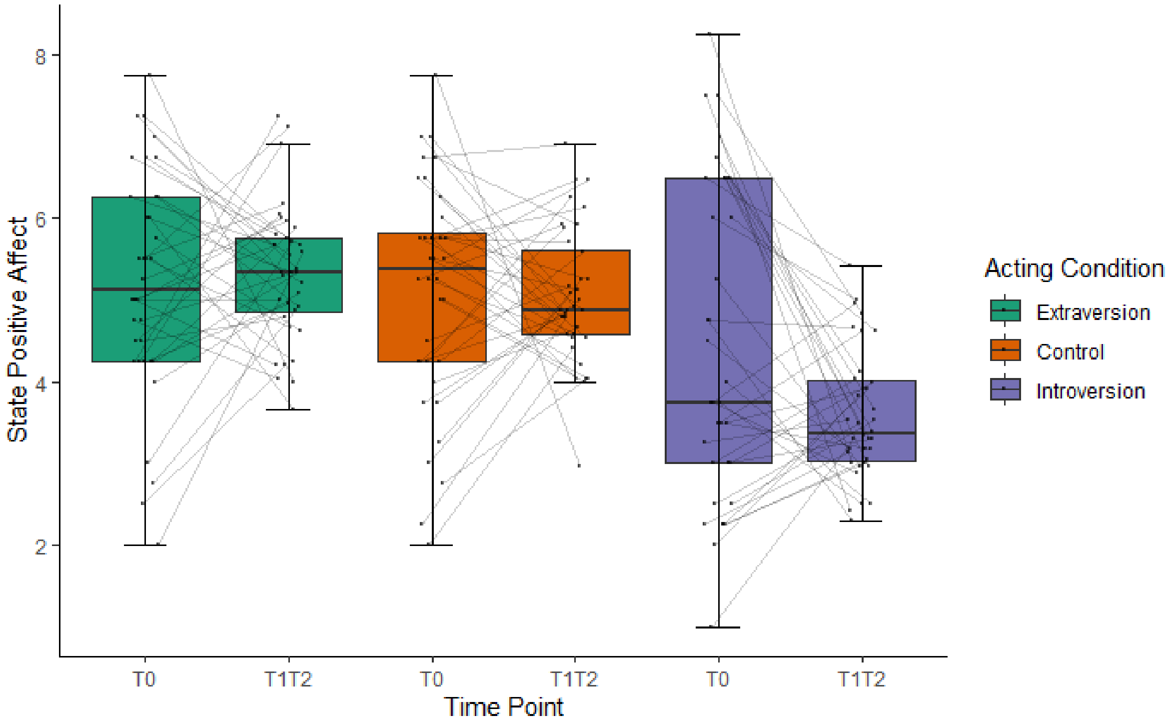
To measure performance, we calculated summary indices as in study 1 (switch cost difference, 3-back target accuracy, 3-back target RTs), which were jointly analyzed in a multivariate multilevel model to account for potential shared task variance as well as participant data nested in groups.

2.3.3 Results

Similar to studies 1 and 2, preliminary analyses revealed unsatisfactory reliability of the switching task's difference score measures (Cronbach's α= .28) , while split-half reliability was good for 3-back accuracy (Rel. = .80) and 3-back RTs (Rel. = .91). The three acting conditions showed the hypothesized effects on state extraversion and state PA, although state PA changed less than expected from baseline to after the discussions, possibly due to a tendency for preexisting (i.e. at baseline) lower state PA in the introversion condition compared to control (*B* = -0.75, *p* = .047; see Figure 7).

Acting condition had no effects on EFs as measured with the 3-back and the switching task. The absence of effects remained consistent across different statistical approaches and after potential confounders were included. While neither state PA nor state extraversion after the discussions, or their interaction with acting condition, explained cognitive performance, additional analyses revealed associations of both trait (agentic) extraversion and baseline state PA with EF task performance.

Figure 7. Boxplots of State Positive Affect as a Function of Acting Condition and Time.



Note. T0 = Baseline measurement; T1T2 = mean of the measurements at T1 and T2 (after group discussions). Change in individual scores from T0 to T1T2 is presented as individual dots connected with lines.

Agentic extraversion (but not the whole scale) was associated with higher flexibility in the switching task ($R = .24$, $p = .014$) and a tendency for slower RTs in the 3-back task ($R = .17$, $p = .081$). When added as covariate into the main model, baseline state PA was associated with higher flexibility in the control condition ($B = 0.23$, $p = .057$), but higher stability in the two acting conditions (introversion: $B = -0.41$, $p = .005$; extraversion: $B = -0.39$, $p = .020$). Regarding the spontaneous EBR, a multilevel model accounting for data nested within groups showed that the introversion condition's descriptive EBR increase was significantly different from the descriptive EBR decrease in the extraversion ($B = 0.27$, $p = .042$) and control condition ($B = 0.33$, $p = .015$).

2.3.4 Discussion

Acting condition elicited the expected effects on PA, but against expectations not on performance measures of the two EF tasks. While the lack of effects of acting condition on EF task performance is surprising given the quite pronounced effects on state extraversion and state PA, other results of study 3 are in line with the findings of studies 1 and 2. More specifically, the repeated finding that the switching task has questionable reliability adds substance to previous doubts on its application in individual differences research. The association between trait extraversion and higher flexibility in the switching task is further compatible with the results of study 1, but not with the null results of study 2. Surprisingly, the association between trait extraversion and slower 3-back responding was in opposite direction of the previously reported positive association in study 1. However, the previous study did not include a discussion task which might have differently activated extraversion-related individual differences, e.g. by prompting extraverts to invest more cognitive resources during the discussion, which could afterwards have impeded performance in the quite demanding 3-back task (but not in the less demanding switching task). Despite their exploratory nature, the changes in spontaneous EBR in opposite directions for the extraversion and introversion condition could be taken to indicate that acting condition somewhat affected striatal DA activation (based on the hypothetical assumption that the spontaneous EBR is a valid indicator for it).

In summary, we successfully manipulated state extraversion and state PA, but found no effects of this manipulation on EF task performance. Instead, additional analyses revealed associations between trait extraversion and task performance, which could be taken to indicate that the discussion task may have activated extraverted-related individual differences in EF task performance, but that extraversion-EF associations are not directional in the sense that state (and perhaps also trait) extraversion would causally affect EFs. It remains open whether a reverse causal effect (individual differences in EFs also partly manifesting as extraversion) exists, and further research is needed to confirm the current preliminary finding, ideally with a more reliable measure for stability-flexibility.

3. General Discussion

The investigation of personality traits, cognitive processes, and their potential shared neural mechanisms requires an approach which draws from several subdisciplines of psychology. This integrative perspective can not only help to understand intersections among, for example, cognitive and differential psychology, but might also provide fruitful new perspectives within each of them. The current project is based on the view that research on the neural mechanisms behind extraversion can profit from the extensive amount of research on the neural structure and mechanisms regulating EFs, for instance by drawing from established concepts and methodological knowledge. We aimed to investigate the relationship between trait/state extraversion and EFs, and its modulation/association with DA in three studies. By including either a pharmacological manipulation of DA activation, or a behavioral manipulation of state extraversion, we aimed to approach the notion of a shared dopaminergic basis of extraversion and EFs from two directions. In studies 1 and 2, we expected trait extraversion to be associated with individual differences in EF task performance, and expected this effect to be sensitive to manipulations of DA activation. In study 3, we expected enacted extraversion (versus introversion) to explain individual differences in PA, EF task performance and explored the change in the spontaneous EBR as a putative marker of striatal DA activation.

We found the expected relationship between trait extraversion and EFs in study 1 and, although not hypothesized because we had expected acting condition effects to dominate, also in study 3. However, as the higher powered, preregistered study 2 neither found the expected extraversion-EF associations, nor a dopaminergic modulation, the present findings should be viewed as preliminary. The switching task's low reliability throughout all three studies should further be kept in mind as a general limitation of the current results. Against expectations, we further did not find evidence for a modulation of EFs through enacted extraversion versus introversion, or indirectly through state PA. This speaks against the hypothesis of a causal effect of state extraversion as a proxy for trait extraversion on EFs, which may indicate that manipulations of state extraversion are not isomorphic to trait extraversion effects, or that there is no causal effect from extraversion to EFs. The lack of state effects on EFs is rather surprising given the effects we found on the spontaneous EBR in the same study, albeit limited by their exploratory nature and the insecure status of the EBR as an indicator for striatal DA activation (Dang et al., 2017; Sescousse et al., 2018). In conclusion, we found suggestive evidence for extraversion-EF associations, mixed results for a potential shared dopaminergic basis, and no indication for a causal effect of state extraversion on EFs.

3.1 Implications

The current findings have implications for the relationship between extraversion and EFs, as well as their hypothesized shared dopaminergic basis. The mixed results of the three studies can have several explanations with different implications, which will be discussed in the following.

The current project's mixed results could indicate that the relationship between extraversion and EFs, or shared dopaminergic mechanisms behind it, are smaller than expected, from which would follow that previous studies have overestimated effect sizes and that the current studies are underpowered. At least for study 2, however, it seems rather unlikely that insufficient power caused the complete absence of the expected effects. While the power to find effects in the switching task and AX-CPT of study 2 was limited by their low reliabilities, the 3-back task showed good reliability and power should have been sufficient to find a small effect. Similarly, it seems unlikely that power was insufficient in study 3, at least for the reliable 3-back task, as the sample size was again planned to be sufficient for finding a small effect. In light of the fact that we indeed found the expected quite large effect sizes in state PA (but still not in EFs), a complete absence of acting condition effects on EFs due to smaller true effects seems quite unlikely. As the switching task (and AX-CPT) did not show sufficient reliability in any of the studies, however, it remains possible that power to find effects in these tasks was insufficient. Still, this would not explain the lack of findings for the 3-back task, unless the true association between extraversion and EF updating is very small, which would cast doubts on the question whether it is worth further research efforts.

It is further possible that we found mixed results because effects were partly masked by third variables which systematically affected results in the three studies, such as factors around fatigue or affective-motivational variables. This explanation is consistent with the results of study 3, in which the group discussion might have activated some form of extraversion-related individual differences in both cognition and behavior. More specifically, the group discussion in study 3 offered the opportunity to be bold, talkative and assertive (partly depending on acting conditions), while study 2, in contrast, might have failed to include a relevant situational context to activate extraversion-related individual differences, which could be why we did not find the expected extraversion-EF associations. If this was the case, it remains open why study 1, which applied an experimental design similar to study 2, still found extraversion-EF associations. At the current point I can only speculate which other factors might have been at play either strengthening the results of study 1, or weakening the results of study 2. Potential factors may include the proactive conservation (or depletion) of cognitive resources due to different study lengths and different tasks completed before the tasks analyzed here, different experimenters which may have created variation in approach-motivation contexts (cf. Wacker et al., 2013), or sex differences in the true effects. Further research with methodological improvements and systematic investigation of potential modulatory factors is needed to answer this question.

In summary, although the current findings are inconsistent, they are suggestive of an underlying relationship between trait extraversion and EFs in two out of three studies. The association between trait extraversion and EFs was demonstrated to be sensitive to a pharmacological modulation of DA in one out of two studies, and enacted extraversion versus introversion was associated with changes in the EBR as a putative marker of striatal DA activation, but still not with EFs. While these suggestive findings do not allow for a definite answer on the notion of shared dopaminergic mechanisms behind extraversion-EF associations and provide no indication for a causal mechanism from (state) extraversion to EF performance, they illustrate the need for further research to understand which factors contribute to the association between extraversion and

EFs. Reliable, replicable extraversion-EF associations on a behavioral level are a prerequisite for examining their sensitivity to dopaminergic modulation. The current results hopefully encourage further research with methodological improvements and systematic variation of potentially confounding variables to replicate stable associations and to better understand the directionality, or even causality, behind extraversion-EF associations.

3.2 Limitations and Methodological Recommendations

Several limitations need to be considered in the light of the current project's results, and more generally, in the context of trait-EF associations. Firstly, appropriating cognitive tasks (developed with the goal to investigate general cognitive effects similar for all individuals) for individual differences research can pose a fundamental problem if reliability is not considered. Potential correlations between a cognitive task and another variable, such as a personality trait, are limited in size by their individual reliabilities (Hedge et al., 2018; Spearman, 1904). Cognitive tasks could have a low reliability even if they perfectly measured a robust cognitive phenomenon, because they are designed to maximize within-participant variance while minimizing between-participant variance (Hedge et al., 2018). A low reliability does therefore not necessarily stem from high measurement variance but can be inherent in the task's design (Hedge et al., 2018; Herrmann & Wacker, 2021). To my knowledge, the current project's studies are the first to report reliability indices for the switching task, and its low reliability limits the current results as well as its further application in individual differences research. The problem of limited reliability is not new in the context of EF tasks, and has been ascribed to the nature of the tasks: As they are designed to measure the ability to cope with new problems, task performance can vary considerably over time, potentially due to increasingly automated processing and variation in strategy use (Jurado & Rosselli, 2007; Miyake et al., 2000). However, the current switching task's reliability is even lower than the limited reliabilities discussed in previous studies on other EF tasks. Even in the light of these limited reliabilities, the switching task would still need to be methodologically adapted to be acceptable for individual differences research, for example by increasing the number of switches and/or by fostering faster responding in order to create higher between-participant variance, ideally in combination with several other EF tasks to extract more reliable latent variables (Friedman & Miyake, 2017). Another option might be the use of psychometrically evaluated and normed EF tasks from test batteries, e.g. from the Cambridge Neuropsychological Test Automated Battery (CANTAB; Haring et al., 2015) or the NIH Toolbox (Hodes et al., 2013), albeit these come with the disadvantage of not providing all the different components of EFs in line with current models (Snyder et al., 2015).

Secondly, associations between EF tasks and personality (or a lack thereof) are limited by the complex interplay of cognitive processes EF tasks involve which do not tap the targeted EF. This includes shared variance among tasks due to shared lower-level processes such as letter processing (i.e. task impurity), and more general shared EF processes (i.e. task unity). Furthermore, a valid and reliable measurement of a specific function requires its exact definition. However, there is yet no consensus on the core processes behind several EFs, as some authors argue that shifting is in fact a special case of updating, not a specific function of its own (Kessler et al 2017). The n-back task, as a measure for updating, also entails variance from other, more generic working memory processes which encode, maintain, and retrieve representations (Singh et al., 2018), and has been shown to be a valid measure for both working memory updating and capacity (Frischkorn et al., 2022; Schmiedek et al., 2009). It therefore remains unclear which of these processes the task's association with extraversion can be ascribed to. Generally, the investigation of cognitive mechanisms behind EF task performance faces the problem that performance likely is a product of several, interacting processes involving actual capacity, motivation, and the ability to control both (Musslick et al., 2018). As these various mechanisms behind task performance probably are cognitively costly, they are assumed to require motivation as a regulator to save or expand resources (Aarts et al., 2011; Cools, 2016). It has for example been found that higher striatal DA does not directly increase flexibility, but that it increases, as a response to incentives, the motivation to invest cognitive effort (Cools, 2016; Westbrook & Braver, 2016). Following this argument, extraverts might perform better in EF tasks because of higher motivation for good task performance (cf. Wacker, 2018), not because of actually higher capacity, which would also be in line with extraverts' higher incentive motivation. Further studies, ideally with a large set of reliable EF tasks drawing on different lower-level processes, and a latent variable approach in their analysis, are necessary to clarify previous problems regarding potential shared variance, task impurity and reliability issues. Broader approaches to tackle conceptual unclarities and the influence of motivational processes will be discussed in "Future Directions".

Thirdly, pharmacological designs as in the current project do not allow for precise inferences about neural areas involved. Conclusions about the role of *striatal* DA for the relationship between extraversion and EFs should be made with caution, because (1) pharmacological manipulations can have various, partly paradoxical, consequences by indirectly affecting other neural regions, for example a modulation of striatal DA also affects the balance with prefrontal DA (Cools & D'Esposito, 2011), (2) it is possible that DA signaling is not homogeneous across the striatum (Westbrook et al., 2021), which would make holistic theories on striatal DA functioning based on the current data imprecise even if a pharmacological manipulation could only affect striatal DA activation, (3) even if a drug exclusively binds with DA-receptors, the resulting change in activation can have differential effects depending on other neurotransmitter systems involved in EFs and extraversion, such as the opioid system (Chiew, 2021; Wacker & Smillie, 2015). Although yet not connected to extraversion, there further is growing evidence for an overlap and interaction of DA and norepinephrine systems, which could be related to arousal effects on stability-flexibility (Chiew, 2021) and could thus also be involved in differential effects of DA affecting drugs. It should further be noted that metabolization of sulpiride can differ considerably between individuals, resulting in quite large variation of peak serum levels (Mauri et al., 1996) and potential systematic effects on cognitive tasks (cf. Eisenegger et al., 2014).

Lastly, although research findings should ideally generalize to a broad population, variation in several potential confounding variables needs to be minimized especially in the early stages of research on a specific question. The currently recruited samples of young, healthy adults (mostly university students) are therefore quite homogeneous regarding age, ethnic background, education and intelligence. It is possible that variation in personality variables as well as EF task performance is larger in a broader population (e.g. representative for Germany), which could potentially produce stronger correlations. Other confounding factors might however dilute effects, for instance how experienced individuals are with experimental contexts and operating on computers, or how motivated and interested they are in a group discussion task. The current findings should therefore not yet be taken to be generalizable to a broader population without further research.

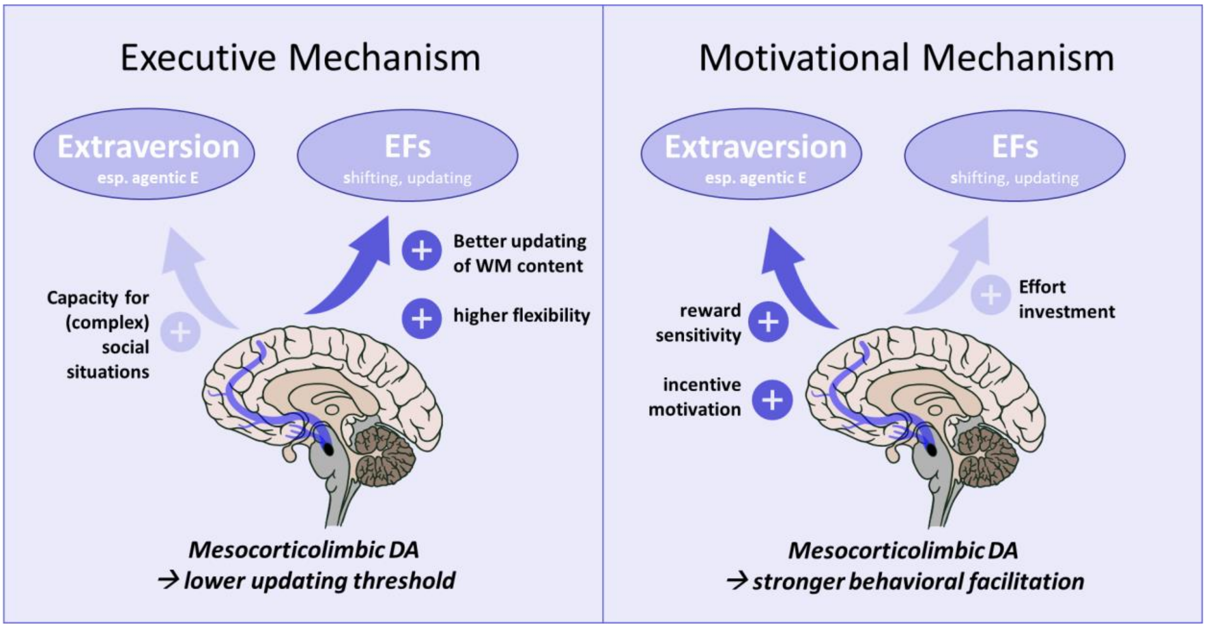
3.3 Future Directions

Approaching personality research from a cognitive and/or neuroscientific perspective offers the potential for explanatory models of personality traits. As the field of personality neuroscience is rather new, more detailed theories can be expected as the field progresses (DeYoung & Blain, 2020). In relation to the current project, there are several lines of potential research questions on the intersection among personality, cognitive, and affective-motivational processes.

More formalized, mechanistic models are needed to generate quantitative hypotheses, and although such models might need several more years of research to allow for accurate predictions, it should be noted that computational models which produce individual differences in task performance similar to humans already exist, for example for a (albeit slightly different) shifting task (Herd et al., 2014), the n-back task (Chatham et al., 2011), for the decision to exert cognitive control (Shenhav et al., 2013) and for the role of affect on cognitive control (Grahek et al., 2020). Using these models to perform simulations with variation in different model components could reveal which model component produces performance variation similar to what is found in studies on extraversion-EF associations. Such models might also help to better understand the directionality, or even causality, of extraversion-EF associations, as it currently remains unclear whether individual differences in EFs also partly manifest as extraversion, or reversely, whether individual differences in extraversion partly manifest as EFs, or whether both are regulated by shared neural mechanisms without affecting each other. Needless to say, all approaches based on computational simulations require an ample amount of human behavioral data with stable extraversion-EF associations to conduct reliable comparisons.

The emerging perspective that cognitive control must be motivated because it is inherently costly to exert it (Cools, 2016) offers several new possibilities in the context of research on extraversion-EF associations. Motivation to exert control, and therefore increase cognitive effort during task performance, is the product of several interacting factors around capacity, costs and benefits (Shenhav et al., 2013). For instance in the n-back task, striatal DA seems to promote cognitive control, and thus task performance, by increasing sensitivity its benefits, and decreasing sensitivity its costs (Westbrook et al., 2020). If performance in EF tasks is partly regulated by motivational factors, and extraversion is also associated with motivation, extraversion-EF associations could not only be attributed to executive processes behind task performance ("executive mechanism"), such as better updating ability, but also to motivational components, such

Figure 8. Two Potential Shared Neural Mechanisms Behind Extraversion-EF Associations.



Note. **Left panel:** Mesocorticolimbic dopamine (DA) could affect both extraversion, especially its agentic component, and executive functions (EFs) through a lower updating threshold, which affects EFs (dark blue arrow) and, rather indirectly, could also foster flexibility or higher capacity to navigate social situations (light blue arrow). **Right panel:** Alternatively, both could be affected by DA through stronger behavioral facilitation, which is the core of extraversion (dark blue arrow) and could further affect motivation for cognitive effort in EF tasks (light blue arrow).

as higher sensitivity to the benefits of employing cognitive control ("motivational mechanism", Figure 8).

Mechanistic models such as the "Expected Value of Control" model (EVC model; Shenhav et al., 2013) set parameters such as control capacity, reward magnitude and control costs against each other to form the decision to (not) employ cognitive effort. A computational model built upon this EVC model is able to produce decision patterns similar to humans (Lieder et al., 2018). As an approach to disentangling these decision parameters in the context of extraversion-EF associations, future studies could include effort discounting tasks based on cost-benefit decisions, for example regarding cognitive effort (Westbrook et al., 2021) or physical effort (Ohmann et al., 2022), as additional tasks next to more commonly applied EF tasks. Although effort discounting also reflects variation in the above named other model parameters, as well as other factors potentially related to capacity, e.g. need for cognition (Westbrook et al., 2013), strategy use and motoric abilities (Ohmann et al., 2022), and have yet not reliably been connected to extraversion (Ohmann et al., 2020), individual differences in effort discounting might still reflect motivational factors to a higher degree compared to other EF tasks. A joint analysis of effort discounting and EF tasks, ideally with latent variable approaches, offers the opportunity to replicate previous findings and gain further understanding of the interplay between executive and motivational mechanisms for task performance. Another approach might be to conduct simulations with the computational models built upon the EVC model to produce individual differences in EF task performance similar to those associated with extraversion. For instance, extraverts might perceive the benefits of employing effort as more positive, which influences their decision on how much cognitive effort should be employed, which in turn affects task performance. This approach invites a more mechanistic understanding of how motivational processes can shape EF task performance, and could thus be helpful to generate new hypotheses and experimental paradigms on extraversion-related cognitive performance differences.

Somehow connected to the previously discussed potential motivational factors behind EF task performance, effects of positive emotion on cognition and decision-making may be moderated by distinctions among specific positive emotions (Shiota et al., 2017). Previous research on the modulatory role of high versus low approach motivated PA (Dreisbach & Fröber, 2019), or wanting-expectancy versus warmth-liking (Wacker, 2018) on stability-flexibility could be seen as a examples for this. Future studies with a more detailed measurement or manipulation of affective-motivational states are needed to investigate distinct effects on different EFs, e.g. of high versus low arousal PA, performance contingent versus non-contingent rewards, or personality state enactments. Such investigations might also help to understand mixed results of previous studies on extraversion-EF associations and the question whether effects are specific to the agentic component of extraversion or not. Again, formalized models on interactions between affect, motivation and cognition to generate and test quantitative predictions (Grahek et al., 2020) are needed to gain a more mechanistic understanding of these interacting processes and the role of state/trait extraversion.

Individual differences in EF task performance, and their affective-motivational modulation, might not be extraversion-specific but also associated with other traits. Most importantly, trait openness has also been connected to DA in the context of creativity and divergent thinking (Käckenmester et al., 2019), and individual differences in striatal DA have even been hypothesized to be connected to creative cognition due to increased flexibility via higher striatal DA activation (although flexibility was defined in a broader sense; Boot et al., 2017). While this explanation entails partly the same mechanisms as hypothesized for extraversion, it should be noted that the current project does not indicate an overlap of extraversion and openness regarding the cognitive mechanisms they are each hypothesized to be associated with, as (1) effects reported in study 1 remained significant even after controlling for openness, (2) openness was not associated with EF task performance in study 2, and (3) in another part of the dataset form study 2, Käckenmester et al. (2019) report openness effects which remained significant after controlling for extraversion. While these findings should be viewed as preliminary, they are compatible with the unifying theory of DA as a “neuromodulator of exploration”, which posits that DA is released to attain rewards (connected to extraversion) or information (connected to openness; DeYoung, 2013) via two different neural DA pathways. Apart from openness, trait neuroticism might also be considered due to its negative association with EF updating (Murdock et al., 2013), more error-prone EF performance (Crow, 2019), and in the context of positive affective-motivational states due to its strong association with negative affect (Costa & McCrae, 1980), which might at least explain some variation in the effects of positive affective state manipulations. Future research should go beyond a mere demonstration of a stable explanatory role for task performance of one trait after partialling out variance of the respective other trait, for example by including neuroimaging techniques. Individual differences in neural activation in candidate areas could be investigated *during* task performance, for example during tasks targeting EFs and creative cognition, to test whether the two tasks can dissociate neural activation in the respective putative DA pathways of extraversion and openness, and whether this activation can explain performance in interaction with the respective trait.

To better understand previously mixed results of pharmacological manipulations, future studies could directly consider the dose- and baseline-dependent effects of DA agonists and antagonists. Direct measurement of plasma concentrations, e.g. of sulpiride, could predict behavioral effects more precisely compared to a dichotomous predictor of substance versus placebo (cf. Eisenegger et al., 2014). Positron emission tomography (PET) measures of DA baseline activation, such as striatal synthesis capacity and receptor availability, could further help to predict whether a certain plasma concentration improves or impairs task performance (cf. Westbrook et al., 2020). At first glance, implementing such approaches in within-subject designs would allow for a more detailed assessment of dose- and baseline-dependent pharmacological effects, and generally increases statistical power, but it should also be considered that a within-subject approach would likely come at the cost of reduced EF task reliability due to increased automated processing and strategy use over time (i.e. with repeated measurements of EFs).

Lastly, the replication crisis has revealed several problems in the field of psychological and neuroscientific research, such as methodological and statistical problems, which have cast doubts on the reproducibility and replicability of previous findings (Open Science Collaboration, 2015; Simmons et al., 2011). But even without the replication crisis being one of the most prominent topics in psychological science, the field of research of the current project is in need of adequately powered studies to produce reliable results. Many of the above mentioned research endeavors require copious amounts of resources which can be problematic as these are hardly manageable for one lab alone. A promising solution are collaborative approaches, in which several labs collectively generate hypotheses, preregister analyses, collect data and publish results (Wacker, 2017). Although collaborative approaches are also resource-intense in the sense that they require intense communication and preparation among labs, they allow investigations in considerably larger samples. They further have the potential to produce higher-quality, reproducible research, and by this, contribute substantially to the open science movement and to good scientific practice (Wacker, 2017).

3.4 Conclusion

Individual differences in general cognitive mechanisms are not just error variance which needs to be eradicated, but can be used as a window on cognitive structure (Friedman & Miyake, 2017). Associations between variation in these effects with trait variables, such as extraversion, can inform about underlying cognitive and potentially biological mechanisms. Knowledge about these associations, as well as their sensitivity to manipulations of neural transmission or affective-motivational states, is therefore not only helpful to better understand individual differences in general cognitive effects, but also to gain insight into the neurobiological basis of personality. The current project indicates that DA plays a role in extraversion-EF associations in two out of three studies, by showing their sensitivity to a pharmacological modulation of DA study 1, and with enacted extraversion versus introversion leading to changes in the EBR as a putative marker of striatal DA activation in study 3. The current findings are also inconsistent, as we found no indication for extraversion-EF associations in study 2, and no indication for a causal effect of state extraversion on EFs in study 3. These mixed findings might be explained by potential modulatory mechanisms of third variables, such as affective-motivational states, and/or by several methodological limitations.

Stable, theory-consistent associations between extraversion and cognitive measures are a prerequisite for finding reliable results when pharmacologically manipulating those associations. Moreover, associations between extraversion and cognitive performance cannot be clearly inferred from individual differences in task performance without considering the role of motivational variables. It is therefore important for future research of this field to include reliable EF tasks, consider task reliability in power calculations, and systematically investigate potential moderating variables. The current results hopefully encourage further research which, on the long-term, moves the field towards more formalized, mechanistic models built upon a solid theoretical foundation. Ideally in combination with computational simulations of extraversion-related individual differences in EF task performance, such models are needed to go beyond showing the existence of an effect and towards quantitative predictions. The role of DA for the interplay between cognition and motivation has been an emerging perspective in cognitive neuroscience literature for the past years (Aarts et al., 2011; Cools et al., 2019), and personality neuroscience could profit from further implementing this perspective. Combining cognitive and personality neuroscience approaches has the potential to bring these two disciplines closer together and allow for a comprehensive view on individual differences.

References

Aarts, E., van Holstein, M., & Cools, R. (2011). Striatal Dopamine and the Interface between Motivation and Cognition. *Frontiers in Psychology*, *2*, 163. https://doi.org/10.3389/fpsyg.2011.00163

Arendasy, M., Hornke, L. F., Sommer, M., Wagner-Menghin, M., Gittler, G., Häusler, J., Bognar, B., & Wenzl, M. (2012). *Intelligenz-Struktur-Batterie (INSBAT)* (27th ed.). Schuhfried GmbH.

Arias-Carrión, O., Stamelou, M., Murillo-Rodríguez, E., Menéndez-González, M., & Pöppel, E. (2010). Dopaminergic reward system: A short integrative review. *International Archives of Medicine*, *3*(1), 24. https://doi.org/10.1186/1755-7682-3-24

Baik, S., Yoon, H. S., Kim, S. E., & Kim, S. H. (2012). Extraversion and striatal dopaminergic receptor availability in young adults. *NeuroReport*, *23*(4), 251–254. https://doi.org/10.1097/WNR.0b013e3283507533

Berse, T., Barenberg, J., Urban, V., & Dutke, S. (2014). Agentic extraversion moderates the effect of physical exercise on executive shifting performance. *Journal of Research in Personality*, *52*, 37–41. https://doi.org/10.1016/j.jrp.2014.06.007

Blain, S. D., Sassenberg, T. A., Xi, M., Zhao, D., & DeYoung, C. G. (2021). Extraversion but not depression predicts reward sensitivity: Revisiting the measurement of anhedonic phenotypes. *Journal of Personality and Social Psychology*, *121*(2), e1-e18. https://doi.org/10.1037/pspp0000371

Boot, N., Baas, M., van Gaal, S., Cools, R., & Dreu, C. K. W. de (2017). Creative cognition and dopaminergic modulation of fronto-striatal networks: Integrative review and research agenda. *Neuroscience and Biobehavioral Reviews*, *78*, 13–23. https://doi.org/10.1016/j.neubiorev.2017.04.007

Brose, A., Lövdén, M., & Schmiedek, F. (2014). Daily fluctuations in positive affect positively co-vary with working memory performance. *Emotion (Washington, D.C.)*, *14*(1), 1–6. https://doi.org/10.1037/a0035210

Campbell, A. M., Davalos, D. B., Mccabe, D. P., & Troup, L. J. (2011). Executive functions and extraversion. *Personality and Individual Differences*, *51*(6), 720–725. https://doi.org/10.1016/j.paid.2011.06.018

Carpenter, S. M., Peters, E., Västfjäll, D., & Isen, A. M. (2013). Positive feelings facilitate working memory and complex decision making among older adults. *Cognition & Emotion*, *27*(1), 184–192. https://doi.org/10.1080/02699931.2012.698251

Cattell, R., & Weiß, R. (1971). *Grundintelligenztest Skala 3 (CFT3)*. Hogrefe.

Chiew, K. S. (2021). Revisiting positive affect and reward influences on cognitive control. *Current Opinion in Behavioral Sciences*, *39*, 27–33. https://doi.org/10.1016/j.cobeha.2020.11.010

Chiew, K. S., & Braver, T. S. (2017). Context processing and cognitive control. In *The Wiley Handbook of Cognitive Control* (pp. 143–166). https://doi.org/10.1002/9781118920497.ch9

Cools, R. (2016). The costs and benefits of brain dopamine for cognitive control. *Wiley Interdisciplinary Reviews: Cognitive Science*, *7*(5), 317–329. https://doi.org/10.1002/wcs.1401

Cools, R. (2019). Chemistry of the Adaptive Mind: Lessons from Dopamine. *Neuron*, *104*(1), 113–131. https://doi.org/10.1016/j.neuron.2019.09.035

Cools, R., & D'Esposito, M. (2011). Inverted-U-shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry*, *69*(12), e113-e125. https://doi.org/10.1016/j.biopsych.2011.03.028

Cools, R., Froböse, M., Aarts, E., & Hofmans, L. (2019). Dopamine and the motivation of cognitive control. *Handbook of Clinical Neurology*, *163*, 123–143. https://doi.org/10.1016/B978-0-12-804281-6.00007-0

Cools, R., & Robbins, T. W. (2004). Chemistry of the adaptive mind. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, *362*(1825), 2871–2888. https://doi.org/10.1098/rsta.2004.1468

Cooper, A. J., Duke, É., Pickering, A. D., & Smillie, L. D. (2014). Individual differences in reward prediction error: contrasting relations between feedback-related negativity and trait measures of reward sensitivity, impulsivity and extraversion. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00248

Corr, P. J., & Cooper, A. J. (2016). The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ): Development and Validation. *Psychological Assessment*, *28*(2), 418–427. https://doi.org/10.1037/pas0000273

Costa, P. T., & McCrae, R. R. (1980). Influence of extraversion and neuroticism on subjective well-being: happy and unhappy people. *Journal of Personality and Social Psychology*, *38*(4), 668–678. https://doi.org/10.1037/0022-3514.38.4.668

Crow, A. J. D. (2019). Associations Between Neuroticism and Executive Function Outcomes: Response Inhibition and Sustained Attention on a Continuous Performance Test. *Perceptual and Motor Skills*, *126*(4), 623–638. https://doi.org/10.1177/0031512519848221

Dang, L. C., Samanez-Larkin, G. R., Castrellon, J. J., Perkins, S. F., Cowan, R. L., Newhouse, P. A., & Zald, D. H. (2017). Spontaneous Eye Blink Rate (EBR) Is Uncorrelated with Dopamine D2 Receptor Availability and Unmodulated by Dopamine Agonism in Healthy Adults. *ENeuro*, *4*(5). https://doi.org/10.1523/ENEURO.0211-17.2017

Depue, R. A., & Collins, P. F. (1999). Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences*, *22*(3), 491–569. https://doi.org/10.1017/S0140525X99002046

Depue, R. A., & Fu, Y. (2013). On the nature of extraversion: Variation in conditioned contextual activation of dopamine-facilitated affective, cognitive, and motor processes. *Frontiers in Human Neuroscience*, *7*, 288. https://doi.org/10.3389/fnhum.2013.00288

DeYoung, C. G. (2013). The neuromodulator of exploration: A unifying theory of the role of dopamine in personality. *Frontiers in Human Neuroscience*, *7*, Article 762, 1–26. https://doi.org/10.3389/fnhum.2013.00762

DeYoung, C. G., & Blain, S. D. (2020). Personality Neuroscience. In P. J. Corr & G. Matthews (Eds.), *The Cambridge Handbook of Personality Psychology* (2nd ed., pp. 273–292). Cambridge University Press. https://doi.org/10.1017/9781108264822.026

Doll, B. B., & Frank, M. J. (2009). The basal ganglia in reward and decision making. In J.-C. Dreher & L. Tremblay (Eds.), *Handbook of reward and decision making* (pp. 399–425). Academic Press. https://doi.org/10.1016/B978-0-12-374620-7.00019-4

Dreisbach, G. (2006). How positive affect modulates cognitive control: The costs and benefits of reduced maintenance capability. *Brain and Cognition*, *60*(1), 11–19. https://doi.org/10.1016/j.bandc.2005.08.003

Dreisbach, G., & Fröber, K. (2019). On How to Be Flexible (or Not): Modulation of the Stability-Flexibility Balance. *Current Directions in Psychological Science*, *28*(1), 3–9. https://doi.org/10.1177/0963721418800030

Dreisbach, G., & Goschke, T. (2004). How positive affect modulates cognitive control: reduced perseveration at the cost of increased distractibility. *Journal of Experimental Psychology: Learning Memory and Cognition*, *30*(2), 343–353. https://doi.org/10.1037/0278-7393.30.2.343

Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K.-P., & Brocke, B. (2005). Dopamine and Cognitive Control: The Influence of Spontaneous Eyeblink Rate and Dopamine Gene Polymorphisms on Perseveration and Distractibility. *Behavioral Neuroscience*, *119*(2), 483–490. https://doi.org/10.1037/0735-7044.119.2.483

Ecker, U. K., Lewandowsky, S., & Oberauer, K. (2014). Removal of information from working memory: A specific updating process. *Journal of Memory and Language*, *74*, 77–90. https://doi.org/10.1016/j.jml.2013.09.003

Ecker, U. K., Lewandowsky, S., Oberauer, K., & Chee, A. E. (2010). The Components of Working Memory Updating: An Experimental Decomposition and Individual Differences. *Journal of*

Experimental Psychology: Learning Memory and Cognition, *36*(1), 170–189. https://doi.org/10.1037/a0017891

Eisenegger, C., Naef, M., Linssen, A., Clark, L., Gandamaneni, P. K., Müller, U., & Robbins, T. W. (2014). Role of dopamine D2 receptors in human reinforcement learning. *Neuropsychopharmacology*, *39*(10), 2366–2375. https://doi.org/10.1038/npp.2014.84

Eysenck, H. J. (1959). The "Maudsley Personality Inventory" as determinant of neurotic tendency and extraversion. *Zeitschrift Für Experimentelle Und Angewandte Psychologie*, 167–190.

Eysenck, H. J. (1967). *The biological basis of personality*. Thomas.

Fallon, S. J., Kienast, A., Muhammed, K., Ang, Y.-S., Manohar, S. G., & Husain, M. (2019). Dopamine D2 receptor stimulation modulates the balance between ignoring and updating according to baseline working memory ability. *Journal of Psychopharmacology*, *33*(10), 1254–1263. https://doi.org/10.1177/0269881119872190

Figueira, J. S. B., Pacheco, L. B., Lobo, I., Volchan, E., Pereira, M. G., Oliveira, L. de, & David, I. A. (2018). "Keep That in Mind!" The Role of Positive Affect in Working Memory for Maintaining Goal-Relevant Information. *Frontiers in Psychology*, *9*, 1228. https://doi.org/10.3389/fpsyg.2018.01228

Fleeson, W., Malanos, A. B., & Achille, N. M. (2002). An intraindividual process approach to the relationship between extraversion and positive affect: is acting extraverted as "good" as being extraverted? *Journal of Personality and Social Psychology*, *83*(6), 1409–1422. https://doi.org/10.1037/0022-3514.83.6.1409

Frank, M. J., & O'Reilly, R. C. (2006). A mechanistic account of striatal dopamine function in human cognition: Psychopharmacological studies with cabergoline and haloperidol. *Behavioral Neuroscience*, *120*(3), 497–517. https://doi.org/10.1037/0735-7044.120.3.497

Friedman, N. P., Du Pont, A., Corley, R. P., & Hewitt, J. K. (2018). Longitudinal Relations Between Depressive Symptoms and Executive Functions From Adolescence to Early Adulthood: A Twin

Study. *Clinical Psychological Science : A Journal of the Association for Psychological Science*, *6*(4), 543–560. https://doi.org/10.1177/2167702618766360

Friedman, N. P., & Miyake, A. (2017). Unity and Diversity of Executive Functions: Individual Differences as a Window on Cognitive Structure. *Cortex*, *86*, 186–204. https://doi.org/10.1126/science.1249098.Sleep

Friedman, N. P., Miyake, A., Young, S. E., Defries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual Differences in Executive Functions Are Almost Entirely Genetic in Origin. *Journal of Experimental Psychology*, *137*(2), 201–225. https://doi.org/10.1037/0096-3445.137.2.201

Frischkorn, G. T., Bastian, C. C. von, Souza, A. S., & Oberauer, K. (2022). Individual differences in updating are not related to reasoning ability and working memory capacity. *Journal of Experimental Psychology. General.* Advance online publication. https://doi.org/10.1037/xge0001141

Fröber, K., & Dreisbach, G. (2014). The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control. *Cognitive, Affective and Behavioral Neuroscience*, *14*(2), 530–547. https://doi.org/10.3758/s13415-014-0259-x

Fulmer, C. A., Gelfand, M. J., Kruglanski, A. W., Kim-Prieto, C., Diener, E., Pierro, A., & Higgins, E. T. (2010). On “feeling right” in cultural contexts: How person-culture match affects self-esteem and subjective well-being. *Psychological Science*, *21*(11), 1563–1569. https://doi.org/10.1177/0956797610384742

Grahek, I., Musslick, S., & Shenhav, A. (2020). A computational perspective on the roles of affect in cognitive control. *International Journal of Psychophysiology*, *151*, 25–34. https://doi.org/10.1016/j.ijpsycho.2020.02.001

Gratton, G., Cooper, P., Fabiani, M., Carter, C. S., & Karayanidis, F. (2018). Dynamics of cognitive control: Theoretical bases, paradigms, and a view for the future. *Psychophysiology*, *55*(3). https://doi.org/10.1111/psyp.13016

Gray, J. A. (1970). The psychophysiological basis of introversion-extraversion. *Behaviour Research and Therapy*, *8*(3), 249–266. https://doi.org/10.1016/0005-7967(70)90069-0

Gray, J. R. (2001). Emotional modulation of cognitive control: Approach-withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of Experimental Psychology: General*, *130*(3), 436–452. https://doi.org/10.1037//0096-3445.130.3.436

Gray, J. R., & Braver, T. S. (2002). Personality predicts working-memory-related activation in the caudal anterior cingulate cortex. *Cognitive, Affective and Behavioral Neuroscience*, *2*(1), 64–75. https://doi.org/10.3758/CABN.2.1.64

Haring, L., Mõttus, R., Koch, K., Trei, M., & Maron, E. (2015). Factorial validity, measurement equivalence and cognitive performance of the Cambridge Neuropsychological Test Automated Battery (CANTAB) between patients with first-episode psychosis and healthy volunteers. *Psychological Medicine*, *45*(9), 1919–1929. https://doi.org/10.1017/S0033291714003018

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods*, *50*(3), 1166–1186. https://doi.org/10.3758/s13428-017-0935-1

Herrmann, W., & Wacker, J. (2021). The Selective Dopamine D2 Blocker Sulpiride Modulates the Relationship Between Agentic Extraversion and Executive Functions. *Cognitive, Affective and Behavioral Neuroscience*, *21*(4), 852–867. https://doi.org/10.3758/s13415-021-00887-9

Hodes, R. J., Insel, T. R., & Landis, S. C. (2013). The NIH toolbox: Setting a standard for biomedical research. *Neurology*, *80*(11 Suppl 3), S1. https://doi.org/10.1212/WNL.0b013e3182872e90

Jacques-Hamilton, R., Sun, J., & Smillie, L. D. (2018). Costs and Benefits of Acting Extraverted: A Randomized Controlled Trial. *Journal of Experimental Psychology: General*, *148*(9), 1538–1556. https://doi.org/10.1037/xge0000516

Jebb, R. C. (1870). *The Characters of Theophrastus*. Macmillan and Co.

Jongkees, B. J., & Colzato, L. S. (2016). Spontaneous eye blink rate as predictor of dopamine-related cognitive function—A review. *Neuroscience and Biobehavioral Reviews*, *71*, 58–82. https://doi.org/10.1016/j.neubiorev.2016.08.020

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understanding. *Neuropsychology Review*, *17*(3), 213–233. https://doi.org/10.1007/s11065-007-9040-z

Käckenmester, W., Bott, A., & Wacker, J. (2019). Openness to experience predicts dopamine effects on divergent thinking. *Personality Neuroscience*, *2*. https://doi.org/10.1017/pen.2019.3

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. *Psychological Bulletin*, *144*(11), 1147–1185. https://doi.org/10.1037/bul0000160

Kim, S. H., Hwang, J. H., Park, H. S., & Kim, S. E. (2008). Resting brain metabolic correlates of neuroticism and extraversion in young men. *NeuroReport*, *19*(8), 883–886. https://doi.org/10.1097/WNR.0b013e328300080f

Kuroki, T., Meltzer, H. Y., & Ichikawa, J. (1999). Effects of antipsychotic drugs on extracellular dopamine levels in rat medial prefrontal cortex and nucleus accumbens. *The Journal of Pharmacology and Experimental Therapeutics*, *288*(2), 774–781.

Lai, H., Wang, S., Zhao, Y., Zhang, L., Yang, C., & Gong, Q. (2019). Brain gray matter correlates of extraversion: A systematic review and meta-analysis of voxel-based morphometry studies. *Human Brain Mapping*, *40*(14), 4038–4057. https://doi.org/10.1002/hbm.24684

Lappin, J. M., Reeves, S. J., Mehta, M. A., Egerton, A., Coulson, M., & Grasby, P. M. (2009). Dopamine release in the human striatum: motor and cognitive tasks revisited. *Journal of Cerebral Blood Flow & Metabolism*, *29*(3), 554–564. https://doi.org/10.1038/jcbfm.2008.146

Lemire-Rodger, S., Lam, J., Viviano, J. D., Stevens, W. D., Spreng, R. N., & Turner, G. R. (2019). Inhibit, switch, and update: A within-subject fMRI investigation of executive control. *Neuropsychologia*, *132*, 1–12. https://doi.org/10.1016/j.neuropsychologia.2019.107134

Li, M., Wei, D., Yang, W., Zhang, J., & Qiu, J. (2019). Neuroanatomical correlates of extraversion. *NeuroReport*, *30*(14), 953–959. https://doi.org/10.1097/WNR.0000000000001306

Lieberman, M. D., & Rosenthal, R. (2001). Why introverts can't always tell who likes them: multitasking and nonverbal decoding. *Journal of Personality and Social Psychology*, *80*(2), 294. https://doi.org/10.1037/0022-3514.80.2.294

Lieder, F., Shenhav, A., Musslick, S., & Griffiths, T. L. (2018). Rational metareasoning and the plasticity of cognitive control. *PLoS Computational Biology*, *14*(4), e1006043. https://doi.org/10.1371/journal.pcbi.1006043

Lucas, R. E., & Baird, B. M. (2004). Extraversion and emotional reactivity. *Journal of Personality and Social Psychology*, *86*(3), 473–485. https://doi.org/10.1037/0022-3514.86.3.473

Lucas, R. E., Diener, E., Grob, A., Suh, E. M., & Shao, L. (2000). Cross-cultural evidence for the fundamental features of extraversion. *Journal of Personality and Social Psychology*, *79*(3), 452–468. https://doi.org/10.1037/0022-3514.79.3.452

Lucas, R. E., & Fujita, F. (2000). Factors influencing the relation between extraversion and pleasant affect. *Journal of Personality and Social Psychology*, *79*(6), 1039–1056. https://doi.org/10.1037/0022-3514.79.6.1039

Luciana, M., Depue, R. A., Arbisi, P., & Leon, A. (1992). Facilitation of Working Memory in Humans by a D2 Dopamine Receptor Agonist. *Journal of Cognitive Neuroscience*, *4*(1), 58–68. https://doi.org/10.1162/jocn.1992.4.1.58

Margolis, S., & Lyubomirsky, S. (2020). Experimental manipulation of extraverted and introverted behavior and its effects on well-being. *Journal of Experimental Psychology. General*, *149*(4), 719–731. https://doi.org/10.1037/xge0000668

Mauri, M. C., Bravin, S., Bitetto, A., Rudelli, R., & Invernizzi, G. (1996). A risk-benefit assessment of sulpiride in the treatment of schizophrenia. *Drug Safety*, *14*(5), 288–298. https://doi.org/10.2165/00002018-199614050-00003

McCrae, R. R., & Costa, P. T. (1987). Validation of the five-factor model of personality across instruments and observers. *Journal of Personality and Social Psychology*, *52*(1), 81–90. https://doi.org/10.1037//0022-3514.52.1.81

Miller, E. K., & Cohen, J. D. (2001). An Integrative Theory of Prefrontal Cortex Function. *Annual Review of Neuroscience*, *24*(1), 167–202.

Miyake, A., & Friedman, N. P. (2012). The Nature and Organisation of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, a. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134–140. https://doi.org/10.1016/s1364-6613(03)00028-7

Mueller, E. M., Burgdorf, C., Chavanon, M.-L., Schweiger, D., Hennig, J., Wacker, J., & Stemmler, G. (2014). The COMT Val158Met polymorphism regulates the effect of a dopamine antagonist on the feedback-related negativity. *Psychophysiology*, *51*(8), 805–809. https://doi.org/10.1111/psyp.12226

Mueller, E. M., Burgdorf, C., Chavanon, M.-L., Schweiger, D., Wacker, J., & Stemmler, G. (2014). Dopamine modulates frontomedial failure processing of agentic introverts versus extraverts in incentive contexts. *Cognitive, Affective and Behavioral Neuroscience*, *14*(2), 756–768. https://doi.org/10.3758/s13415-013-0228-9

Müller, J., Dreisbach, G., Brocke, B., Lesch, K.-P., Strobel, A., & Goschke, T. (2007). Dopamine and cognitive control: The influence of spontaneous eyeblink rate, DRD4 exon III polymorphism and gender on flexibility in set-shifting. *Brain Research*, *1131*(1), 155–162. https://doi.org/10.1016/j.brainres.2006.11.002

Müller, J., Dreisbach, G., Goschke, T., Hensch, T., Lesch, K.-P., & Brocke, B. (2007). Dopamine and cognitive control: The prospect of monetary gains influences the balance between flexibility and stability in a set-shifting paradigm. *European Journal of Neuroscience*, *26*(12), 3661–3668. https://doi.org/10.1111/j.1460-9568.2007.05949.x

Murdock, K. W., Oddi, K. B., & Bridgett, D. J. (2013). Cognitive Correlates of Personality: Links Between Executive Functioning and the Big Five Personality Traits. *Journal of Individual Differences*, *34*(2), 97–104. https://doi.org/10.1027/1614-0001/a000104

Musslick, S., Cohen, J. D., & Shenhav, A. (2018). Estimating the costs of cognitive control from task performance: theoretical validation and potential pitfalls. In *Proceedings of the 40th Annual Meeting of the Cognitive Science Society* (pp. 800–805). Cognitive Science Society.

Neo, P. S.-H., McNaughton, N., & Sellbom, M. (2021). Early and late signals of unexpected reward contribute to low extraversion and high disinhibition, respectively. *Personality Neuroscience*, *4*, e5. https://doi.org/10.1017/pen.2021.4

O'Gorman, R. L., Kumari, V., Williams, S. C., Zelaya, F. O., Connor, S. E., Alsop, D. C., & Gray, J. A. (2006). Personality factors correlate with regional cerebral perfusion. *10538119*, *31*(2), 489–495. https://doi.org/10.1016/j.neuroimage.2005.12.048

Ohmann, H. A., Kuper, N., & Wacker, J. (2020). A low dosage of the dopamine D2-receptor antagonist sulpiride affects effort allocation for reward regardless of trait extraversion. *Personality Neuroscience*, *3*. https://doi.org/10.1017/pen.2020.7

Ohmann, H. A., Kuper, N., & Wacker, J. (2022). Examining the reliability and validity of two versions of the Effort-Expenditure for Rewards Task (EEfRT). *PloS One*, *17*(1), e0262902. https://doi.org/10.1371/journal.pone.0262902

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. *Science*, *349*(6251), aac4716. https://doi.org/10.1126/science.aac4716

Owen, A. M., Roberts, A. C., Hodges, J. R., & Robbins, T. W. (1993). Contrasting mechanisms of impaired attentional set-shifting in patients with frontal lobe damage or Parkinson's disease. *Brain*, *116*(5), 1159–1175. https://doi.org/10.1093/brain/116.5.1159

Parsons, S., Kruijt, A.-W., & Fox, E. (2019). Psychological Science Needs a Standard Practice of Reporting the Reliability of Cognitive-Behavioral Measurements. *Advances in Methods and Practices in Psychological Science*, *2*(4), 378–395. https://doi.org/10.1177/2515245919879695

Paul, K., Pourtois, G., van Steenbergen, H., Gable, P., & Dreisbach, G. (2021). Finding a balance: modulatory effects of positive affect on attentional and cognitive control. *Current Opinion in Behavioral Sciences*, *39*, 136–141. https://doi.org/10.1016/j.cobeha.2021.03.002

Reineberg, A. E., Gustavson, D. E., Benca, C., Banich, M. T., & Friedman, N. P. (2018). The Relationship Between Resting State Network Connectivity and Individual Differences in Executive Functions. *Frontiers in Psychology*, *9*, 1600. https://doi.org/10.3389/fpsyg.2018.01600

Robinson, M. D., Moeller, S. K., & Ode, S. (2010). Extraversion and reward-related processing: Probing incentive motivation in affective priming tasks. *Emotion*, *10*(5), 615–626. https://doi.org/10.1037/a0019173

Schäfer, T., & Schwarz, M. A. (2019). The Meaningfulness of Effect Sizes in Psychological Research: Differences Between Sub-Disciplines and the Impact of Potential Biases. *Frontiers in Psychology*, *10*, 813. https://doi.org/10.3389/fpsyg.2019.00813

Schimmack, U., Radhakrishnan, P., Oishi, S., Dzokoto, V., & Ahadi, S. (2002). Culture, personality, and subjective well-being: Integrating process models of life satisfaction. *Journal of Personality and Social Psychology*, *82*(4), 582–593. https://doi.org/10.1037/0022-3514.82.4.582

Schmiedek, F., Hildebrandt, A., Lövdén, M., Wilhelm, O., & Lindenberger, U. (2009). Complex span versus updating tasks of working memory: The gap is not that deep. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, *35*(4), 1089–1096. https://doi.org/10.1037/a0015730

Sescousse, G., Ligneul, R., van Holst, R. J., Janssen, L. K., Boer, F. de, Janssen, M., Berry, A. S., Jagust, W. J., & Cools, R. (2018). Spontaneous eye blink rate and dopamine synthesis capacity: Preliminary evidence for an absence of positive correlation. *The European Journal of Neuroscience*, *47*(9), 1081–1086. https://doi.org/10.1111/ejn.13895

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*, *79*(2), 217–240. https://doi.org/10.1016/j.neuron.2013.07.007

Shiota, M. N., Campos, B., Oveis, C., Hertenstein, M. J., Simon-Thomas, E., & Keltner, D. (2017). Beyond happiness: Building a science of discrete positive emotions. *The American Psychologist*, *72*(7), 617–643. https://doi.org/10.1037/a0040456

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2011). False-positive psychology: Undisclosed flexibility in data collection and analysis allows presenting anything as significant. *Psychological Science*, *22*(11), 1359–1366. https://doi.org/10.1177/0956797611417632

Singh, K. A., Gignac, G. E., Brydges, C. R., & Ecker, U. K. (2018). Working memory capacity mediates the relationship between removal and fluid intelligence. *Journal of Memory and Language*, *101*, 18–36. https://doi.org/10.1016/j.jml.2018.03.002

Smillie, L. D. (2013). Why Does It Feel Good To Act Like an Extravert? *Social and Personality Psychology Compass*, *7*(12), 878–887. https://doi.org/10.1111/spc3.12077

Smillie, L. D., Cooper, A. J., & Pickering, A. D. (2011). Individual differences in reward-prediction-error: Extraversion and feedback-related negativity. *Social Cognitive and Affective Neuroscience*, *6*(5), 646–652. https://doi.org/10.1093/scan/nsq078

Smillie, L. D., DeYoung, C. G., & Hall, P. J. (2015). Clarifying the Relation Between Extraversion and Positive Affect. *Journal of Personality*, *83*(5), 564–574. https://doi.org/10.1111/jopy.12138

Smillie, L. D., Jach, H. K., Hughes, D. M., Wacker, J., Cooper, A. J., & Pickering, A. D. (2019). Extraversion and reward-processing: Consolidating evidence from an electroencephalographic index of reward-prediction-error. *Biological Psychology*, *146*, 107735. https://doi.org/10.1016/j.biopsycho.2019.107735

Smillie, L. D., & Wacker, J. (2014). Dopaminergic foundations of personality and individual differences. *Frontiers in Human Neuroscience*, *8*, 5–7. https://doi.org/10.3389/fnhum.2014.00874

Smillie, L. D., Wilt, J. A., Kabbani, R., Garratt, C., & Revelle, W. (2015). Quality of social experience explains the relation between extraversion and positive affect. *Emotion*, *15*(3), 339–349. https://doi.org/10.1037/emo0000047

Smith, E. E., & Jonides, J. (1997). Working memory: A view from neuroimaging. *Cognitive Psychology*, *33*(1), 5–42. https://doi.org/10.1006/cogp.1997.0658

Snyder, H. R., Miyake, A., & Hankin, B. L. (2015). Advancing understanding of executive function impairments and psychopathology: Bridging the gap between clinical and cognitive approaches. *Frontiers in Psychology*, *6*, 328. https://doi.org/10.3389/fpsyg.2015.00328

Spearman, C. (1904). The Proof and Measurement of Association between Two Things. *The American Journal of Psychology*, *15*(1), 72. https://doi.org/10.2307/1412159

Stemmler, G. (1997). Selective activation of traits: Boundary conditions for the activation of anger. *Personality and Individual Differences*, *22*(2), 213–233. https://doi.org/10.1016/S0191-8869(96)00189-4

Storbeck, J., Dayboch, J., & Wylie, J. (2018). Fear and happiness, but not sadness, motivate attentional flexibility: A case for emotion influencing the ability to split foci of attention. *Emotion*, *19*(4), 655. https://doi.org/10.1037/emo0000471

Sun, J., Stevenson, K., Kabbani, R., Richardson, B., & Smillie, L. D. (2017). The Pleasure of Making a Difference: Perceived Social Contribution Explains the Relation Between Extraverted Behavior and Positive Affect. *Emotion*, *17*(5), 794–810. https://doi.org/10.1037/emo0000273 van Allen, Z. M., Walker, D. L., Streiner, T., & Zelenski, J. M. (2021). Enacted Extraversion as a Well-Being Enhancing Strategy in Everyday Life: Testing Across Three, Week-Long Interventions. *Collabra: Psychology*, *7*(1), Article 29931. https://doi.org/10.1525/collabra.29931

Vaughan, R. S., & Edwards, E. J. (2020). Executive function and personality: The moderating role of athletic expertise. *Personality and Individual Differences*, *161*, 1–7. https://doi.org/10.1016/j.paid.2020.109973

Wacker, J. (2017). Increasing the Reproducibility of Science through Close Cooperation and Forking Path Analysis. *Frontiers in Psychology*, *8*, Article 1332. https://doi.org/10.3389/fpsyg.2017.01332

Wacker, J. (2018). Effects of positive emotion, extraversion, and dopamine on cognitive stability-flexibility and frontal EEG asymmetry. *Psychophysiology*, *55(1)*, 1–16. https://doi.org/10.1111/psyp.12727

Wacker, J., Chavanon, M.-L., & Stemmler, G. (2006). Investigating the Dopaminergic Basis of Extraversion in Humans: A Multilevel Approach. *Journal of Personality and Social Psychology*, *91*(1), 171–187. https://doi.org/10.1037/0022-3514.91.1.171

Wacker, J., Mueller, E. M., Pizzagalli, D. A., Hennig, J., & Stemmler, G. (2013). Dopamine-D2-Receptor Blockade Reverses the Association Between Trait Approach Motivation and Frontal Asymmetry in an Approach-Motivation Context. *Psychological Science*, *24*(4), 489–497. https://doi.org/10.1177/0956797612458935

Wacker, J., & Smillie, L. D. (2015). Trait Extraversion and Dopamine Function. *Social and Personality Psychology Compass*, *9*(6), 225–238. https://doi.org/10.1111/spc3.12175

Westbrook, A., & Braver, T. S. (2016). Dopamine Does Double Duty in Motivating Cognitive Effort. *Neuron*, *89*, 695–710. https://doi.org/10.1016/j.neuron.2016.07.020

Westbrook, A., Frank, M. J., & Cools, R. (2021). A mosaic of cost-benefit control over cortico-striatal circuitry. *Trends in Cognitive Sciences*, *25*(8), 710–721. https://doi.org/10.1016/j.tics.2021.04.007

Westbrook, A., Kester, D., & Braver, T. S. (2013). What is the subjective cost of cognitive effort? Load, trait, and aging effects revealed by economic preference. *PloS One*, *8*(7), e68210. https://doi.org/10.1371/journal.pone.0068210

Westbrook, A., van den Bosch, R., Määttä, J. I., Hofmans, L., Papadopetraki, D., Cools, R., & Frank, M. J. (2020). Dopamine promotes cognitive effort by biasing the benefits versus costs of cognitive work. *Science*, *367*(6484), 1362–1366. https://doi.org/10.1126/science.aaz5891

Wilt, J. A., & Revelle, W. (2009). Extraversion. In M. R. Leary & R. H. Hoyle (Eds.), *Handbook of individual differences in social behavior* (pp. 27–45). Guilford Press.

Yang, H., Yang, S., & Isen, A. M. (2013). Positive affect improves working memory: Implications for controlled cognitive processing. *Cognition & Emotion*, *27*(3), 474–482. https://doi.org/10.1080/02699931.2012.713325

Yee, D. M., & Braver, T. S. (2018). Interactions of motivation and cognitive control. *Current Opinion in Behavioral Sciences*, *19*, 83–90. https://doi.org/10.1016/j.cobeha.2017.11.009

Zelenski, J. M., Santoro, M. S., & Whelan, D. C. (2012). Would introverts be better off if they acted more like extraverts? Exploring emotional and cognitive consequences of counterdispositional behavior. *Emotion*, *12*(2), 290–303. https://doi.org/10.1037/a0025169

Appendix A

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RESEARCH ARTICLE

The Selective Dopamine D2 Blocker Sulpiride Modulates the Relationship Between Agentic Extraversion and Executive Functions

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Abstract

Initial studies suggest that agentic extraversion and executive functions (EF) are associated, because they share influences of individual differences in the dopamine (DA) system. However, it is unclear whether previously reported associations are specific to certain EFs (e.g., to updating or shifting) or due to shared variance among EF tasks. We investigated the DA-related relationship between agentic extraversion and two EF tasks in a placebo-controlled between-group design with the DA D2 receptor blocker sulpiride (200 mg) in 92 female volunteers. Our goals were to investigate whether (1) there is an association between agentic extraversion and EFs measured with two different tasks (3-back and switching), (2) this association is sensitive to a pharmacological manipulation of DA, and (3) the effects can be ascribed to shared or specific task variance. We observed the expected interaction between drug condition and agentic extraversion for both tasks in a multivariate multiple linear regression model, which supports the DA theory of extraversion. Subsequent univariate analyses revealed a highly similar interaction effect between drug condition and agentic extraversion on two of three performance measures and this effect was somewhat attenuated when we controlled for shared task variance. This pattern matches the interpretation that the association between agentic extraversion and both tasks is partly due to DA-based processes shared among the tasks. Our results, although limited by the low reliability of the switching task, suggest that variance components and measurement difficulties of EF tasks should be considered when investigating personality-related individual differences in EFs.

Keywords Cognitive control · Dopamine · Extraversion · Executive functions

Introduction

According to a prominent psychobiological theory of extraversion, individual differences in extraversion, especially in its agentic component comprising reward responsiveness, assertiveness, activity, drive, and ambitiousness, are partly driven by individual differences in dopaminergic reward and incentive processing (Depue & Collins, 1999). Dopamine has been associated with several other processes, including executive functions (EFs), such as working memory updating (Luciana et al., 1992) and shifting (Fallon et al., 2015). Initial studies suggest that individual differences in these EFs might likewise be associated with extraversion (Lieberman & Rosenthal, 2001), prompting the idea of an overlap in the underlying dopaminergic mechanisms. However, the overall number of studies on the relationship between (agentic) extraversion and EFs is limited, and we are not aware of any studies on the dopaminergic relationship between extraversion and EFs employing more than one EF task within the same study. This constitutes a significant limitation, because—as we will review in more detail in the next section—EF tasks are known to not only target one isolated mechanism. Systematic performance variance in EF tasks is comprised of (1) variance shared by all EF tasks, (2) variance only shared by tasks targeting a specific EF, (3) variance not related to any EF but to other cognitive processes the task recruits (e.g. processing of colors, numbers, or faces). On a neural level, these different sources of performance variance are reflected in a complex system of several interacting areas, including the prefrontal cortex, parietal cortex, and the basal ganglia (Friedman & Miyake, 2017).

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The measurement difficulties of EFs caused by the several variance components in EF task performance are often addressed with a simultaneous analysis of performance in several EF tasks, e.g., with latent variable analysis, in order to differentiate variance components (Friedman & Miyake, 2017). This quite time-intensive approach seems less common for the investigation of third-variable associations, although one EF task alone cannot separate individual differences within each of the variance components of task performance. It is therefore possible that previous studies overestimated the specificity of reported associations between agentic extraversion and EF task performance, which could not only be attributable to the targeted particular EFs (i.e., updating and shifting) but also to other systematic variance components. For the investigation of a relationship between agentic extraversion and EFs, it is necessary to take shared task-variance into consideration.

Executive Functions

Despite a large body of relevant research, the definition and measurement of specific EFs still is a challenging task (Miyake & Friedman, 2012). EFs are understood as top-down control mechanisms that regulate the dynamics of human cognition and action. These mechanisms substantially correlate but also seem to tap into distinct mechanisms, being described as showing both “unity” and “diversity.” Further measurement difficulties arise from the fact that EF tasks must operate on a specific task context (e.g., processing of faces, colors or letters) and therefore necessarily include systematic variance not related to the targeted EF—a phenomenon termed “task impurity.” In order to at least partly cancel out task impurity, EFs often are measured with several tasks operating on different task contexts so that their shared variance can be extracted in a latent variable approach (Miyake & Friedman, 2012). The resulting latent EF variables will still correlate substantially, which demonstrates that performance in EF tasks is not only comprised of variance specific to the EF that was targeted (diversity) but also of shared variance among all EF tasks (unity).

The diversity of EFs also is reflected in differential third-variable associations between specific EFs and for example intelligence (Friedman et al., 2006), which can even vary in direction once the unity of EFs is partialed out—a principle that also could apply to the previously reported associations with agentic extraversion. Because these theoretically could be due to several systematic variance components, a consideration of these components is necessary to draw conclusions about specific relationships, e.g., between agentic extraversion and shifting (Berse et al., 2014). We are currently aware of only one study that indicates that extraversion-related performance differences can be ascribed to EF-processes, and not just task impurity, by computing mean scores across several EF tasks operating on various task contexts (e.g., colors, geometric shapes, words, affective categories; Campbell et al., 2011). Performance differences were found for updating and shifting tasks, which we will review in the next sections.

Updating

Among the numerous EFs, *updating* is probably the one most often associated with extraversion. EF tasks which target updating require participants to monitor, retrieve, transform, and substitute working memory content (Ecker et al., 2010; Miyake & Friedman, 2012). The two candidate mechanisms specific to the concept of updating are effective gating of information and controlled retrieval from long-term memory (Miyake & Friedman, 2012). The n-back task is a common task in the context of EFs. It is mostly known as a measure for updating because it requires a consecutive buffering of continually changing information (Miyake et al., 2000; Smith & Jonides, 1997). While the 1-back version of the task simply requires participants to decide whether one letter is identical to the one presented directly before, the 2- and 3-back versions are more demanding and draw on several executive processes, like the active maintenance of relevant items and resistance to proactive interference from currently irrelevant items (Chatham et al., 2011). Performance differences associated with the agentic aspect of extraversion only show up in the more complex versions of the n-back task (Gray & Braver, 2002; Lieberman & Rosenthal, 2001; Wacker et al., 2006), indicating that agentic extraversion potentially can be associated with working memory processes rather than the short-term memory processes involved in the 1-back version. A similar pattern was found in another study, where (agentic) extraversion-related performance differences in updating tasks also only occurred in difficult task versions, albeit with different EF tasks (Campbell et al., 2011). Taken together, emerging evidence suggests an association between agentic extraversion and updating.

Shifting

Another EF with a potential association with agentic extraversion is *shifting*. This function reflects processes which direct the attentional focus towards new goals or task-sets. We consider shifting to be synonymous with *switching* and understand both as process-oriented terms tied to the broader concept of *cognitive flexibility*.[1] Cognitive flexibility opposes cognitive stability, that is, the active maintenance of current goals or task-sets (Cools & D’Esposito, 2011; Monsell, 2003).

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[1] In this paper, we will use the term *cognitive flexibility* as a general concept and the term shifting when referring to the more task- and process-oriented *shifting factor*. The term *switching* will only be used when referring to the particular switching task that was used in this study.

For functional behavior, it is important to find a balance between actively maintaining current information and directing the attentional focus towards new information, which also is known as the stability-flexibility-dilemma (Dreisbach, 2006; Jongkees & Colzato, 2016). There is ongoing debate about the definition of EFs, especially regarding the broad concept of cognitive flexibility (Boot et al., 2017). Even the definitions of the rather process-oriented terms updating and shifting seem to share the idea that they entail processes that adaptively update current working memory representations. Kessler et al. (2017) even argue that shifting is a special case of working memory updating and that both functions rely mostly on the same processes that remove irrelevant representations from working memory and update it with newly relevant representations. If this were the case, previously reported third-variable associations between agentic extraversion and either EF might be attributable to the same underlying mechanism(s) (Kessler et al., 2017).

Many set-shifting tasks analyze rapid, frequent switches between two task sets as a measure of flexibility without dissociating the functional advantages and disadvantages of high versus low flexibility. They usually follow the pattern that participants are asked to react to certain stimulus features while ignoring other features (e.g., colors, categories, odd/even numbers). A *switch* between the features participants are asked to focus on results in reaction time costs depending on the strength of participants' prior task-set representations and their ease of transitioning to the new task-set. In every nonswitch trial of the task, participants' performance is optimal if they are able to actively maintain the representation of the current task-set. When a switch becomes necessary because the attentional focus needs to be shifted towards a new task-set (Friedman & Miyake, 2017), costs in reaction times might occur because the focus on the preswitch task hinders disengagement even after the switch. This perseverative behavior would be a sign of relatively low flexibility and might be caused by a high threshold in updating (vs. maintaining) task-set representations. However, switch costs might not only occur because the updating threshold is too high, but also when it is too low. Whereas a low threshold is beneficial for adaptively updating task-set representations, it also comes with a weaker active maintenance of the correct task-set representation, increasing the risk for distraction by irrelevant information. This distractibility would be a sign of too high flexibility and might become even more apparent when the distracting information prompts more attention, because it is new and needs a closer examination (Dreisbach, 2006; Dreisbach & Fröber, 2019; Dreisbach & Goschke, 2004; Goschke & Bolte, 2014).

The *switching task* developed by Dreisbach and Goschke (2004) aims to dissociate the costs and benefits of a bias for updating versus maintaining a task-set with the help of two different switching conditions. These conditions address the described balance between distractibility, hence too active updating of working memory representations, versus perseveration, hence too active maintenance of working memory representations. Although this study cannot provide a solution for the conceptual unclarities regarding updating and shifting, a differentiation between two possible mechanisms behind higher switch costs might be helpful to explain the mixed results of prior studies reporting either a negative relationship between agentic extraversion and cognitive flexibility (Wacker, 2018), a positive relationship (Berse et al., 2014), or no relationship (Murdock et al., 2013; Vaughan & Edwards, 2020). Although the results of prior studies are mixed at best, they are all based on the same idea that a potential association between agentic extraversion and cognitive flexibility might be due to a partly shared dopaminergic regulation.

Neural Mechanisms

EF tasks activate a large, integrated neural network including frontal, cingulate, parietal, and subcortical regions (Niendam et al., 2012). Most elements of this network are shared across most EF tasks due to their unitary function for high-level processing (e.g., frontoparietal network; Reineberg et al., 2018), while some elements are process-specific due to their modular, specialized function only necessary either for certain specific EFs (e.g., lateral PFC regions, amongst others, for shifting attention towards a new goal; Lemire-Rodger et al., 2019) or for processing particular representations of task characteristics (e.g., fusiform face area for face processing; Kanwisher et al., 1997). According to computational models as well as clinical studies, the striatum plays a key role in this neural network by performing a gating function. Via its projections to the cortex within the corticostriatal loop (Doll & Frank, 2009), the striatum regulates the updating of current working memory representations in the prefrontal cortex (Chiew & Braver, 2017; Doll & Frank, 2009). Striatal and prefrontal DA create a dynamic balance, with increased DA levels in the striatum associated with decreased DA levels in the prefrontal cortex, and vice versa (Cools & D'Esposito, 2011). This balance affects the updating versus maintenance of working memory representations, with a DA striatal loop regulating the updating of representations via phasic DA release, and a DA prefrontal cortical loop stabilizing representations via tonic DA release (Cools, 2016; Yee & Braver, 2018).

The balance between striatal and prefrontal DA can be affected by pharmacological manipulation of either of their components, with the direction of effects depending on functionally and regionally specific pharmacological effects (Cools & D'Esposito, 2011). For instance, performance after intake of the DA D2 antagonist sulpiride, which affects DA signaling in the striatum (Sigala et al., 1991), has been shown to depend on striatal DA synthesis capacity (Westbrook et al., 2020). This demonstrates that a dopaminergic drug which affects striatal DA activation can improve shifting performance for individuals with low baseline performance and, conversely, decrease it for individuals with high baseline performance (Cools et al., 2007; Cools & D'Esposito, 2011; Kimberg et al., 1997). Therefore, rather than being linearly associated, striatal DA activation and performance are linked via an inverted U-shaped function.

Extraversion has been associated with individual differences in striatal DA receptor density (Baik et al., 2012) and gray matter volume in the caudate and nucleus accumbens (Lai et al., 2019; Li et al., 2019). A differential reaction to dopaminergic drugs, visible in extraversion-related changes in performance, i.e., performance increments for introverts and performance decrements for extraverts, might therefore be indicative of individual differences in baseline DA. In other words, a potential association between (agentic) extraversion and EF performance, which is sensitive to a pharmacological manipulation of sulpiride, would indicate an overlap in the underlying dopaminergic mechanisms in the striatum.

Investigating the effects of a pharmacological manipulation of DA on more than one EF task within the same study therefore is not only a fruitful approach to differentiate specific and shared EF processes, but also for investigating the potential dopaminergic overlap of EFs and agentic extraversion to further elucidate extraversion's dopaminergic basis.

The Current Research

Taken together, so far, there is initial evidence for an association between agentic extraversion and performance in both n-back tasks and tasks targeting cognitive flexibility. Both associations have been, theoretically and/or experimentally, connected with individual differences in DA: Individual differences in reward/incentive salience processing thought to partly underlie both trait extraversion (Depue & Collins, 1999; Li et al., 2019), and performance differences in the n-back and cognitive flexibility tasks (Berse et al., 2014; Lieberman & Rosenthal, 2001; Wacker, 2018; Wacker et al., 2006) might partly result from shared (dopaminergic) mechanisms. However, all EF tasks rely on a large, integrated neural network and simultaneously tap into several EF and non-EF processes. Because none of the previous studies linking extraversion and EFs have used several tasks to differentiate the unity and diversity of EFs and/or the task impurity problem, it is currently unclear whether we are dealing with several coexisting, specific agentic extraversion-EF associations that also may be due to separable biological sources of variance, or alternatively, with a more general association between agentic extraversion and a unitary component of EF variance common to most EF tasks. Therefore, to extend previous findings on the presumably DA-based relationship between agentic extraversion and EFs, we investigated the association between agentic extraversion and the performance in two EF tasks (3-back letter task, and a color-switching-task with letters and numbers) after administration of either placebo or the selective DA D2 receptor blocker sulpiride.

More specifically, the aims of the current study were to investigate (1) whether there is a relationship between agentic extraversion and EFs measured with either the 3-back and/or the switching task, (2) whether this relationship is sensitive to a manipulation of brain DA, and (3) whether the effects are due to shared or specific task variance in the EF tasks. We expected to find a significant interaction effect between agentic extraversion and condition (sulpiride vs. placebo) on EF task performance in a multivariate model. We further expected to find the same significant interaction effect in univariate models for each of the dependent variables. When controlling for the respective other dependent variables, the effects could either (1) be attenuated or disappear, suggesting that they are (partly) due to shared task variance, or (2) remain of the same magnitude as before, suggesting that they are task-specific to the switching- or to the 3-back task.

Methods

Participants

We analyzed a sample of 92 healthy female volunteers (mean age = 22.6, *SD* = 2.5, range 18-31 years, German natives) who participated in this study in exchange for a financial compensation (€55-€65). This study was part of a larger research project on the neural foundations of personality and emotion (further results can be found in Burgdorf et al., 2015; Mueller, Burgdorf, Chavanon, Schweiger, Hennig, et al., 2014; Mueller, Burgdorf, Chavanon, Schweiger, Wacker, & Stemmler, 2014; Schweiger et al., 2013; Wacker, 2018). A post-hoc sensitivity analysis for a MANOVA with two groups (sulpiride vs. placebo), one predictor (agentic extraversion) and three response variables in G*Power 3 demonstrated that a sample size of $N = 92$ (and analysis-$n = 82$) was sufficient to detect a small to medium effect size of $f^2 = 0.12$ (for analysis-n: $f^2 = 0.14$) with an alpha of 0.05 and a power of 0.80 (Faul et al., 2007). After being recruited on campus, participants came to the lab for a pretesting to check if they met all inclusion criteria (body mass index ≥ 17.5, blood pressure > 90/50, right-handed, unmedicated except for hormonal contraception), and none of the exclusion criteria (self-reported physical impairment, pregnancy, habitual smoking, habitual abuse of drugs or alcohol, psychological disorders now or in the past [assessed with a standardized clinical interview]). All participants reported to be in a romantic heterosexual relationship, which was necessary for a study part reported in Burgdorf et al. (2015). The study protocol was approved by the ethics committee of the German Psychological Society (DGPs).

Manipulation

Participants received either a capsule with 200 mg of the DA D2 receptor blocker sulpiride or a nondistinguishable placebo for oral consumption in a randomized, double-blind between-subjects design. Although sulpiride is a DA blocker, low dosages of sulpiride (50-300 mg) are reported to have DA-increasing effects due to a dose-related overbalance of its binding to presynaptic DA autoreceptors (vs. postsynaptic DA receptors in higher dosages; Mauri et al., 1996; Kuroki et al., 1999).

Questionnaires and Tests

Participants completed the German version of the NEO-PI-R (Ostendorf & Angleitner, 2004). Additionally, participants' romantic partners provided a third-person rating with the respective version of the NEO-PI-R. The two ratings were combined into an average rating of each participants' personality. The self- and partner ratings for all NEO facets correlated significantly (all rs > 0.23, all ps < 0.04), with extraversion displaying the highest correlation ($r(80) = 0.60$, $p < 0.001$). Due to experimenter error/equipment failure, two participants had either a self- or a partner rating (but not both), so that we only used the available version instead of the average of the self- and partner rating. The scores for NEO agentic extraversion were calculated as in prior work as mean scores for the NEO extraversion facets assertiveness and activity (Wacker, 2018). The scores for NEO affiliative extraversion were calculated as mean scores for the NEO facets warmth and gregariousness. Participants also completed the Multidimensional Personality Questionnaire (MPQ; Tellegen & Waller, 2008). The mean score of the z-standardized MPQ scales social potency and achievement was used as an alternative measure for agentic extraversion (Morrone-Strupinsky & Depue, 2004). Participants further completed Cattell's Culture Fair Intelligence Test (CFT 3; Cattell & Weiß, 1971), and several other questionnaires which were of interest for other parts of the project.

Dependent Variables

3-back Task

This task was the exact same version as the 3-back version used by Wacker et al. (2006). Participants were presented 180 trials in total, of which the first 60 trials were practice trials used to determine individual reaction time criteria for response feedback (see below), which were excluded from the analysis. Every trial consisted of one white letter on a black screen presented for 500 ms, followed by a pause of 1,650 ms. Participants were instructed to indicate via mouse button press (left button for *yes*, right button for *no*) whether the presented letter was identical to the letter that was presented three trials before and to respond as fast and accurately as possible. Participants received a standardized verbal feedback (350 ms) on whether their response was *correct*, *incorrect,* or *slow* after each trial to penalize both errors and slow responding (sound files were comparable in length and volume), because verbal task instructions alone may elicit variation in response criteria within and between subjects, causing additional error variance in a potential speed-accuracy-tradeoff (Heitz, 2014). Slow reaction times were defined by being below the 90th percentile of a participant's reaction time distribution in the last 50 practice trials (Wacker et al., 2006). Participants did not receive a *slow* feedback during practice trials. Of 120 trials, only the last 117 trials were evaluated, because the first three letters could, by definition, not be classified as targets. Among the evaluated trials, participants were presented 40 target trials, 65 nontarget trials, and 12 lure trials (1-back and 2-back) in a fixed random order. Lure trials were implemented to elicit top-down behavioral adjustments, prioritizing the recollection of items over responding based on their familiarity (Szmalec et al., 2011).

For our main analysis, we calculated the percentage of correct reactions in target trials (accuracy), as well as mean reaction times (speed) for correct target trials as performance measures. We decided to focus on performance in target trials in order to make our results comparable to a prior study on extraversion effects in the 3-back task (Wacker et al., 2006). A statistical analysis of other performance indices, such as RT variability, discrimination index d', and response bias C will be reported in the Supplement.

Switching Task

We presented six blocks of 60 trials which either contained pairs of letters (A, E, O, U, K, M, R, or S) or numbers (2, 3, 4, 5, 6, 7, 8, or 9) in alternating order, and in varying colors (Müller, Dreisbach, Goschke, et al., 2007). Within each block, one color was constantly set as the target-color and another color as the distractor-color.

For each pair of letters/numbers, one was colored as the target and one as the distractor. Participants were instructed to ignore the distractor and to indicate via button press whether the target was a consonant or a vowel (or an even or uneven number) with the left mouse button representing consonants and even numbers, and the right mouse button representing vowels and uneven numbers. Every trial started with two letters (or numbers) presented above and below the fixation cross until participants gave their response. Correct trials were followed by a pause of 1,000 ms, whereas incorrect trials were followed by a pause of 2,000 ms. After 40 trials of each 60-trial-block, participants were informed via a message on the screen that the target-color will *switch* for the remaining trials (e.g., "Change to red"). This color change happened in two different ways (3 blocks each in alternating order): In the condition *learned irrelevance*, the prior distractor-color now became the target color, and a new color was used as distractor-color. In the condition *perseveration*, the prior target-color now became the distractor-color, and a new color was used as target-color. Participants were instructed to respond as fast as possible while avoiding mistakes. The task started with 20 practice trials in which participants gave responses to the target-letters and numbers without distractors.

The switching task is not as cognitively demanding as the 3-back task, which is visible in low error rates (i.e. 3.2% in Müller, Dreisbach, Brocke, et al., 2007) and little variance in accuracy, especially around the actual switch within each block. Performance differences are therefore mostly reflected in reaction times, which is why we measured task performance with a summary index previously reported for this switching task as a measure of the degree or cognitive flexibility relative to stability (Müller, Dreisbach, Goschke, et al., 2007). For this index, we first computed switch costs as the increase in mean reaction times for the five correct trials directly before versus five correct trials directly after the switch (trial 36-40 and trial 41-45), matching the approach in prior work. Because the previously employed fixed number of five trials around the switch is somewhat arbitrary, we also calculated switch costs for a larger interval around the switch (10 correct trials) as an alternative measure, which is in Table 2 in the Supplement. We then calculated a difference score of mean switch costs in the learned irrelevance condition minus mean switch costs in the perseveration condition.

The switch cost difference is a suitable summary index for individual differences in cognitive flexibility, because it taps into both the costs and benefits of a high versus low updating threshold (Müller, Dreisbach, Brocke, et al., 2007; Müller, Dreisbach, Goschke, et al., 2007). Increased flexibility, hence a low updating threshold, should facilitate the disengagement from prior targets, which is thought to be further supported by a bias towards novel stimuli (Dreisbach et al., 2005). This should be especially beneficial in the perseveration condition because of two mechanisms: 1) a low updating threshold, and therefore a lower "stickiness" of the irrelevant cognitive representation of the previous target color (Herd et al., 2014), should facilitate the disengagement from the previous target color, which becomes the distractor color after the switch. Second, the target color after the switch is a new color, which might be more easily updated with a stronger bias towards novel stimuli. Increased stability; hence a high updating threshold, should in contrast facilitate the focus on the preswitch target by shielding it from interference. Performance is disturbed after the switch when now irrelevant, but "sticky" representations are not cleared out fast enough. Additionally, the higher updating threshold should slow down the transition to the new target color, because new information is not as easily allowed to enter working memory. For the learned irrelevance condition, higher flexibility might still be beneficial to clear out the representation of the previous target color but should also come with a higher distractibility by the novel target color of the distractor. Increased stability should in contrast not be negatively affected by the higher stickiness of the previous target color, because even if it is not yet cleared out of working memory, the color is not presented after the switch and does therefore not need an updated stimulus-response-mapping. Furthermore, a higher updating threshold also might be more beneficial in this condition than in the perseverance condition, because it shields working memory representations from interference by the novel stimulus color of the distractor.

By calculating a difference score between the conditions, we do not focus on differences between individuals within conditions, but on the relative costs and benefits of the conditions within individuals, eliminating variance due to more general individual performance differences. Higher positive difference scores, caused by relatively higher switch costs in the learned irrelevance and lower switch costs in the perseveration condition, should be associated with higher flexibility. Lower or even negative scores should in turn be associated with higher stability.

Procedure

Participants first gave their written informed consent to take part in the study, confirmed they did not consume alcohol, nicotine, or caffeine within the last 12 h, and confirmed that they were not pregnant using a standard test (10 mIU/ml human chorionic gonadotropin hCG, VEDA.LAB, Alençon cedex, France). After a light standardized breakfast, they received a capsule either containing sulpiride (200 mg) or a placebo, and completed various personality questionnaires as well as a test of fluid intelligence. Approximately 1 hour after administration of the capsule participants started with the 3-back task, followed by the switching task. After several other tasks, including an experimental manipulation of positive emotions (between groups) and a test of cognitive flexibility (Wacker, 2018), participants completed a standardized postexperimental interview, received their financial compensation, and left the lab after approximately 5 hours.

Statistical Analysis

We computed a multivariate multiple linear model in order to analyze the effects of condition (placebo vs. sulpiride), agentic extraversion, and their interactions on the performance in the switching and in the 3-back task within one analysis. The significance level was defined as $\alpha = 0.05$. By conducting a multivariate model with an overall *F*-test first, the following univariate F-tests, which are only performed if the overall F-test is significant, are protected against an inflation of the overall error rate (Rencher, 2002).

To analyze the three main outcomes (3-back speed and accuracy, switch cost difference score) in more detail and to compare our findings with previously reported results on the relationship between agentic extraversion and EFs, we afterwards conducted multiple linear models for each of the reported outcomes with a step-wise method.

In a first step, we calculated one model for each outcome with the same predictors as in the multivariate model. In a second step, we added the respective other outcomes and their interactions with condition into the models to analyze whether the effects were specific to the respective task or could be explained by shared performance variance. We then analyzed within-condition correlations (partialing out potential confounding variables) as additional effect size measures on the significant interaction effects of each regression model. We did not include 3-back speed as a covariate into the model with 3-back accuracy as the outcome (and vice versa), because 3-back speed and 3-back accuracy are based on the same task and therefore are not informative concerning the specificity of effects.

Both n-back and switching tasks have several other outcomes, which could be potentially used as performance measures. We therefore report additional analyses using signal detection measures (*d'* and *C*) as well as a measure of RT variability for the 3-back task and variations of switch cost measures (per condition, overall mean switch costs, other intervals around the switch) for the switching task.

Results

Preliminary Analyses

Side Effects and Blindness to Condition

None of the participants reported any adverse side effects in response to the pill they received. As part of a postexperimental interview, the answers of participants in a forced choice question whether or not they thought they had been given the drug were independent of their experimental condition (χ^2 (1, $N = 80$) = 0.74, $p = 0.39$). The self-reported certainty of the 17 participants (on a scale from 0-100%) who guessed that they had been given the drug did not differ significantly between the sulpiride ($M = 62.73$, $SD = 19.79$) and the placebo ($M = 58.33$, $SD = 29.78$) condition ($t(15) = 0.37$, $p = 0.719$). None of the participants who guessed correctly about having received sulpiride reported to be 100% sure. It therefore can be concluded that participants were blind to the experimental conditions.

Preexisting Differences Between Conditions

We did not find any preexisting significant differences between experimental conditions for age ($t(90) = 0.893$, $p = 0.374$), fluid intelligence score ($t(90) = -0.037$, $p = 0.971$), or any of the NEO scales in self- or partner-ratings (all *p*s > 0.10, except the partner rating of agreeableness, $t(89) = -1.90$, $p = 0.06$).

Data Exclusion Based on Task Performance

Inspection of reaction time and accuracy data from the switching and the 3-back task showed that ten participants had to be excluded from the analyses due to incompliance, difficulties with understanding the task, or technical difficulties. In the 3-back task, two participants failed to respond in more than 35% of all 3-back trials, which indicated that they did not comply or had difficulties with the task instructions (while all other participants nearly always gave a response, $M = 99.07\%$, $SD = 0.02$). Four other participants failed to react within their individual response window in more than 25% of all trials (>30 trials), leaving it questionable whether the individual latency criterion had the intended effect on their performance compared to the other participants (mean number of trials with "slow"-feedback for the other participants was $M = 5.67$, $SD = 3.68$). In the switching task, three participants had very high error rates in all pre switch trials of the switching task in one of the conditions (>92%), suggesting a technical problem, and the error rate of one other participant indicated that she did not comply or had difficulties with the task instructions (28.75%; error rates of all other participants were much lower, $M = 5.79\%$, $SD = 3.24$). All cases with invalid data on at least one dependent variable were excluded. This resulted in a final sample of $n = 82$ participants (40 in the placebo and 42 in the sulpiride condition). Descriptive statistics for the NEO-PI-R scale and the two executive functioning tasks for the analysis sample are displayed in Table 1. In order to examine whether or how much our exclusion decisions influenced the results of our main analysis, we performed the main analysis with alternative exclusion decisions in which we (1) did not exclude any participants, (2) did not exclude any participants but transformed the data to achieve normality despite the included outliers, or (3) only made exclusions based on one of the reasons listed above, but not on the respective others. The results of the alternative analyses, although less pronounced, displayed the same pattern and did not yield any additional information (*p*-range for the hypothesized interaction effect: 0.022-0.105). All results of these analyses are displayed in Table 3 in the Supplement.

Table 1 Means and Standard Deviations for the Big Five Domains and for Performance Measures of the Executive Functioning Tasks

		Condition		
		Placebo	Sulpiride	Total
		M (*SD*)	*M* (*SD*)	*M* (*SD*)
NEO-PI-R Scale	Neuroticism	91.92 (18.3)	94.27 (16.7)	93.1 (17.5)
	Extraversion	117.9 (13.8)	122.7 (16.5)	120.4 (15.33)
	Agentic extraversion	18.2 (2.8)	18.1 (4.1)	18.1 (3.5)
	Affiliative extraversion	22.0 (3.1)	23.0 (3.4)	22.5 (3.3)
	Openness	122.6 (11.3)	123.6 (15.2)	123.1 (13.4)
	Agreeableness	116.3 (11.4)	121.7 (14.3)	119.1 (13.2)
	Conscientiousness	125.3 (16.0)	122.2 (20.7)	123.7 (18.5)
Dependent Variables	3-back accuracy	60.4 (17.1)	58.8 (15.9)	59.6 (16.5)
	3-back speed	697.4 (146.3)	683.4 (132.0)	690.3 (138.4)
	Switching task:			
	∆ switch costs	24.8 (76.6)	-3.5 (84.5)	10.3 (81.5)
	Perseveration	29.9 (72.8)	41.7 (71.3)	36.0 (71.9)
	Learned irrelevance	53.5 (68.3)	38.1 (74.9)	45.7 (71.7)
	Total switch costs	41.9(58.8)	39.9 (59.7)	40.9 (58.9)
n		40	42	82

∆ switch costs = switch cost difference (switch costs *perseveration* minus switch costs *learned irrelevance*).

Reliability

The switch cost difference showed clearly unsatisfactory reliability (Cronbach's $\alpha = 0.22$), whereas the reliability for the switch costs per block was higher but still unsatisfactory (Cronbach's $\alpha = 0.41$ for learned irrelevance, and Cronbach´s $\alpha = 0.47$ for perseveration). Reliability was equally low when not taking five but ten trials around the switch into account when calculating switch costs, indicating that the low reliability is not only due to the limited amount of trials included per block. The original goal of the switching task was, like for most other cognitive-behavioral measures, to minimize between-participant variability and maximize within-subject effects (e.g., of reward or positive affect; Dreisbach & Goschke, 2004; Müller, Dreisbach, Goschke, et al., 2007). The undeniably low reliability therefore may not only be a sign of high error variance, but also of relatively low between-subject variability, complicating its application in individual differences research (Hedge et al., 2018). We will further address this issue in the discussion section.

We also calculated the split-half reliability (corrected with the Spearman-Brown prophecy formula) for both measures of the 3-back task, which was excellent for 3-back speed ($Rel = 0.91$) and good for 3-back accuracy ($Rel = 0.83$).

Main Analysis

We calculated an analysis of variance for a multivariate multiple linear regression model with the predictors condition (sulpiride vs. placebo), agentic extraversion, and the interaction between condition and agentic extraversion. We analyzed the effects of the predictors on the three outcome measures *3-back speed*, *3-back accuracy*, and the *switch cost difference* (Table 2). We found a significant main effect for agentic extraversion ($\omega^2 = 0.12$). As expected, multivariate cognitive performance was also significantly explained by an interaction between condition and agentic extraversion ($\omega^2 = 0.13$). In order to understand how shared performance variance among the two tasks influenced task performance, and if the predictors also account for task-specific variance, we next analyzed each of the three outcomes separately with two-step linear models (Table 2).

3-back Task: Accuracy

For 3-back accuracy, we found a significant main effect for agentic extraversion ($\omega^2 = 0.05$) and a significant interaction between condition and agentic extraversion ($\omega^2 = 0.08$) in step 1. The interaction effect was due to a positive correlation between agentic extraversion and 3-back accuracy in the placebo condition ($r(38) = 0.33$, $p = 0.03$) and a correlation in the

Table 2 Multivariate und Univariate Multiple Linear Regression Models

		Multivariate Model			Univariate Models						
						3-back accuracy		3-back speed		Δ switch costs	
Parameter		*df*	*Wilks' λ*	*approx. F*	*df*	F_1	F_2	F_1	F_2	F_1	F_2
Step 1	Condition (placebo vs. sulpiride)	3	0.96	1.04	1	0.20	0.01	0.09	0.07	2.89	3.30
	aE	3	0.85	4.53**	1	5.06*	1.62	2.14	2.01	5.40*	1.83
	Condition * aE	3	0.86	4.15**	1	8.32**	4.46*	0.01	0.04	4.12*	2.76
	Error	76			78						
Step 2	3-back accuracy				1						4.32*
	3-back speed				1						0.22
	Δ switch costs				1		5.41*		0.02		
	Condition * 3-back accuracy				1						7.72**
	Condition * 3-back speed				1						0.09
	Condition * Δ switch costs				1		8.72**		0.58		
	Error				74						

Note. *N* 82; *F1* F-statistics for the step 1 model; *F2* F-statistics for the step 2 model; *aE* Agentic Extraversion; *Δ switch costs* switch cost difference (switch costs perseveration minus switch costs learned irrelevance). Agentic Extraversion was centered within condition

$^{*}p < .05$

$^{**}p < .01$

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

opposite direction in the sulpiride condition ($r(40) = -0.28$, $p = 0.07$; difference: $z = 2.71$, $p = 0.006$; Fig. 1).

It is still unclear at this point whether the significant interaction between condition and agentic extraversion specifically explains performance in 3-back accuracy or whether performance differences are shared among the two tasks. We therefore entered the switch cost difference as a covariate into the model (main effect and first-order interaction with condition) to perform step 2. The interaction between condition and agentic extraversion was attenuated but remained significant ($\omega^2 = 0.04$), while the main effect for agentic extraversion disappeared almost completely ($\omega^2 = 0.01$). Additionally, we found a significant main effect for the switch cost difference ($\omega^2 = 0.05$) and a significant interaction effect between condition and the switch cost difference ($\omega^2 = 0.09$). We examined the interaction effects more closely with partial correlations between agentic extraversion and 3-back accuracy, controlling for the switch cost difference. The correlation decreased somewhat in the placebo condition ($r(38) = 0.20$, $p = 0.22$), and remained nearly unchanged in the sulpiride condition ($r(40) = -0.30$, $p = 0.054$; difference: $z = 2.25$, $p = 0.026$). The interaction effect between condition and the switch cost difference was carried by a positive partial correlation (controlling for agentic extraversion) between 3-back accuracy and the switch cost difference in the placebo condition ($r(38) = 0.35$, $p = 0.028$). This correlation tended to be

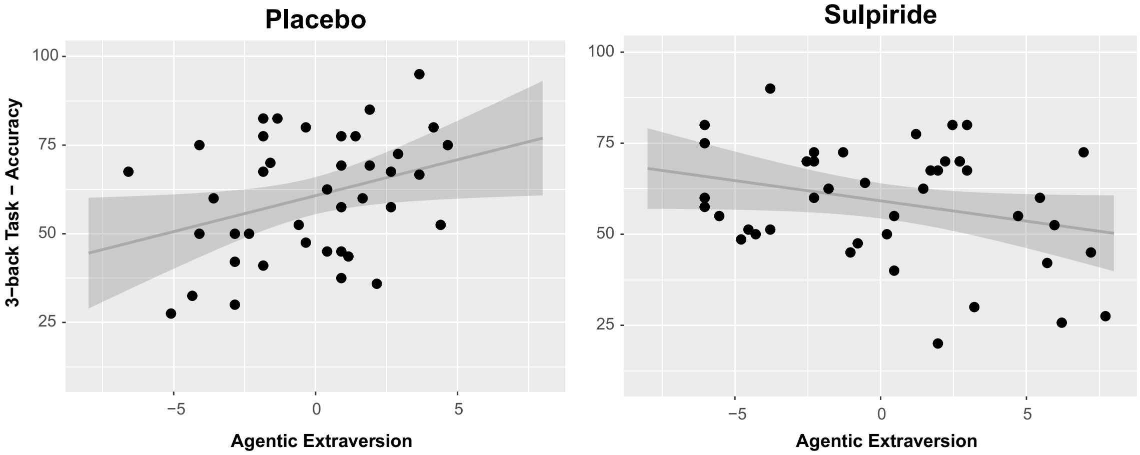

Fig. 1 Scatterplot showing the correlations of agentic extraversion (centered within condition) and accuracy in the 3-back task (in %) with fitted linear regression lines and 95% confidence intervals

reversed for the sulpiride condition ($r(40) = -0.28$, $p = 0.072$, difference: $z = 2.88$, $p = 0.004$).

The significant interaction effect between condition and the switch cost difference on 3-back accuracy, as well as the numeric decrease in the placebo group's significant correlation between agentic extraversion and 3-back accuracy after partialing out the switch cost difference, indicate that the two tasks share some variance. However, neither the effect of agentic extraversion (in interaction with condition) on 3-back accuracy in the linear model, nor their correlation (within conditions), disappeared completely after including the switch cost difference as a covariate. This indicates that the significant interaction between agentic extraversion and condition can partly be ascribed to performance variance shared with the switching task, and partly to variance specific to the 3-back task. The tendency for correlations per condition in opposite directions between 3-back accuracy and the switch cost difference may further suggest a differential sensitivity of the two tasks to sulpiride; however, given that this effect was unexpected it should be regarded as preliminary.

3-back Task: Speed

For 3-back speed, we found no main or interaction effects in either step 1 or 2. Shorter reaction times in correct target trials of the 3-back task were associated with higher agentic extraversion ($r(80) = -0.27$, $p = 0.013$), although this association was not pronounced enough in order have any meaningful effect in the model ($p = 0.15$, $\omega^2 = 0.01$).

Switching Task: Switch Cost Difference

For the switch cost difference, we found a significant main effect for agentic extraversion ($\omega^2 = 0.05$) and a significant interaction between condition and agentic extraversion ($\omega^2 = 0.04$) in step 1. The interaction effect was carried by an association between the switch cost difference and agentic extraversion in the placebo condition, indicating that higher flexibility was correlated with higher agentic extraversion ($r(38) = 0.38$, $p = 0.014$). This association was completely absent in the sulpiride condition ($r(40) = -0.03$, $p = 0.86$), but the difference between correlations for the placebo versus the sulpiride condition failed to reach significance ($z = 1.84$, $p = 0.066$). The correlation between agentic extraversion and the switch cost difference in the placebo condition was equally driven by the two task conditions (perseveration: $r(37) = -0.197$, $p = 0.228$; learned irrelevance: $r(38) = 0.205$, $p = 0.205$).

In order to clarify whether the significant interaction between condition and agentic extraversion specifically explains performance in the switching task, or whether performance differences are shared among the two tasks, we entered the two measures of the 3-back task as covariates into the model (main effects and first-order interactions) in step 2. The interaction effect between condition and agentic extraversion of step 1 was somewhat attenuated ($p = 0.10$, $\omega^2 = 0.02$). The same was found for the main effect for agentic extraversion ($p = 0.18$, $\omega^2 = 0.01$). Besides a significant main effect for 3-back accuracy ($\omega^2 = 0.04$), we found a significant interaction effect between condition and 3-back accuracy ($\omega^2 = 0.08$), mirroring the significant (reverse) interaction effect of condition and the switch cost difference on 3-back accuracy. This interaction effect was carried by the above-mentioned positive partial correlation (controlling for agentic extraversion) between 3-back accuracy and the switch cost difference in the placebo condition, which tended to be reversed for the sulpiride condition. Similar to the pattern on the models for 3-back accuracy, this pattern again suggests that the two tasks share some variance, and that this shared performance variance contributes at least partly to the significant interaction effect between condition and agentic extraversion.

The two conditions of the switching task are designed to capture different cognitive processes, and these processes might be differentially associated with 3-back accuracy. We therefore exploratively investigated correlations between switch costs per condition (learned irrelevance and perseverance) and 3-back accuracy. While there were no significant correlations in the perseverance condition (see Supplement Table 1), we found a clear pattern in the learned irrelevance condition: The positive correlation between 3-back accuracy and learned irrelevance switch costs was quite pronounced in the placebo condition ($r(39) = 0.408$, $p = 0.009$), but absent in the sulpiride condition ($r(39) = -0.165$, $p = 0.297$, difference: $z = 2.54$, $p = 0.011$). This suggests that the learned irrelevance condition drives the association with 3-back accuracy. All pairwise correlations per condition for all task performance indices (including all alternative performance indices) can be found in Table 1 of the Supplement.

Additional Analyses

Specificity to Agentic Extraversion

To investigate whether our findings were specific to agentic extraversion and not explained by other covariates (alternative extraversion measures, all other NEO scales, fluid intelligence or body weight), we recalculated the main multivariate multiple linear regression model separately including one covariate per model (all results are displayed in Table 4 of the Supplement). The previously reported significant effects of agentic extraversion remained significant after entering each covariate, respectively, whereas none of the covariates had significant effects. The exception was, as expected, the model in which we replaced NEO agentic extraversion with an agentic extraversion measure from the MPQ, which displayed the same pattern of significant effects as the main model. Interestingly, the model in which we replaced NEO agentic extraversion with the complete NEO extraversion scale did not reveal any significant effects. Based on these findings, we concluded that our findings were indeed specific to agentic extraversion.

Alternative Performance Indices Derived From the Switching and 3-back Task

As several other performance indices exist for both tasks, we investigated the effects of condition, agentic extraversion, and their interaction on the most commonly reported ones in separate univariate linear regression models in Table 2 in the Supplement (alternative indices for the 3-back task: d', C, total accuracy, RT variability; for the switching task: switch cost difference for ±10 trials around the switch, switch costs for both conditions separately, total switch costs). Reliabilities for the alternative performance indices are depicted in Table 1 in the Supplement. Regarding the alternative 3-back performance indices, we only found a small main effect of agentic extraversion and an interaction effect of condition and agentic extraversion for response bias C. Higher agentic extraversion was associated with a more liberal response bias in the placebo condition ($r(38) = 0.340$, $p = 0.032$), and with a more conservative response bias in the sulpiride condition ($r(40) = -0.324$, $p = 0.036$; difference: $z = 2.93$, $p = 0.003$). This observation fits previous speculations (Wacker et al., 2006) that individual differences in extraversion are rather associated with *how* a task is done and not *how well* it is done. Regarding the alternative indices for the switching task, we only found significant effects on the switch cost difference for ten trials around the switch with a slightly weaker interaction effect ($p = 0.071$), demonstrating that results were not substantially altered by the number of trials around the switch. The fact that none of the other alternative indices revealed any significant effects might further indicate that the focus on the relative costs and benefits in the two conditions within individuals is necessary to investigate predictors of individual differences.

Discussion

The goals of the current study were to investigate (1) whether there is an association between agentic extraversion and EFs measured with either the 3-back and/or the switching task, (2) whether this association is sensitive to manipulations of brain DA, and (3) whether the effects are due to shared or specific task variance in the EF tasks. We found the expected significant interaction effect between agentic extraversion and DA drug condition on EF task performance in a multivariate model. Thus, a pharmacological manipulation of DA D2 receptors only had an effect on EF task performance in interaction with agentic extraversion, but not alone. Furthermore, the univariate analyses showed the expected interaction effect between agentic extraversion and condition on the switch cost difference and on 3-back accuracy, but not on 3-back speed. After controlling for the respective other EF task performance, both interaction effects were somewhat attenuated.

Agentic Extraversion is Associated with Task Performance in the Placebo Condition

We found agentic extraversion to be positively associated with both updating performance measured via 3-back accuracy and cognitive flexibility measured via the switch cost difference in the placebo condition. The positive association between extraversion and 3-back performance matches previous findings with updating tasks (Campbell et al., 2011; Lieberman & Rosenthal, 2001; Wacker et al., 2006). Our additional analysis finding that agentic extraversion was associated with a more liberal response bias in the placebo condition further supports the idea that extraversion-related differences in task performance might not only be due to differences in ability, but in the way the task is performed (Wacker et al., 2006).

Because there are only few existing studies on the association between agentic extraversion and tasks targeting cognitive flexibility, and they revealed mixed results, we view the positive relationship between agentic extraversion and switching performance found in this study with caution. The current study is the first to apply the switching task in a context of extraversion-related individual differences and a direct comparison between this and other measures for cognitive flexibility seems to be missing. It therefore remains unclear whether the current and other tasks measure the underlying construct of cognitive flexibility to a similar extent.

Contrary to Wacker et al. (2006), we did not find any association for 3-back speed, but only for 3-back accuracy. This could indicate that participants of the current study applied a different strategy, potentially because they were only confronted with the 3-back but not easier task versions (0-, 1-, and 2-back). However, given the lack of convergence of the results observed here and by Wacker et al. (2006), the current findings should be regarded as preliminary.

Dopamine Modulates the Relationship Between Agentic Extraversion and Task Performance

The association between agentic extraversion and performance in both tasks was sensitive to sulpiride, which mainly affects DA receptors in the striatum (Sigala et al., 1991). The current data do not speak to the neurophysiological mechanisms underlying this effect but invite the speculation that extraversion-related dopaminergic differences in the striatum might have caused the differential response to sulpiride. More specifically, higher agentic extraversion might be associated with better updating performance and higher flexibility because of higher striatal DA activation, leading to a lower updating threshold (Berse et al., 2014). When striatal DA activation is further enhanced via sulpiride, the updating threshold might be lowered, even to a no longer functional level, which is behaviorally reflected in distractibility. In contrast, the same dopaminergic manipulation might optimize performance for less extraverted people (who start with a higher updating threshold due to lower baseline striatal DA) by beneficially lowering the updating threshold without reaching the point of distractibility (Fig. 2). Our data partly support this notion because we found a matching pattern for the switch cost difference in the switching task and for accuracy (but not speed) in the 3-back task. Although this explanation would match our data, there are several alternative explanations. Individuals high versus low in agentic extraversion might not differ in striatal DA activation, but might be differentially sensitive towards changes in the balance between D1 and D2 receptor activation, or more generally to changes in DA levels, because of individual differences in other neural structures within the corticostriatal loop (Doll & Frank, 2009). Sulpiride might further not only have an effect on cognitive control itself, but also on the motivation to exert it (Cools et al., 2019).

The two tasks seemed to differ in their sensitivities to sulpiride, as the placebo group´s positive association between agentic extraversion and flexibility in the switching task was significantly lower in the sulpiride condition but was not reversed like in the 3-back task.

Considering that DA alterations can have a variety of effects across different tasks and domains (Floresco, 2013), it remains unclear whether such differential sulpiride effects on the two tasks should be ascribed to differential neural mechanisms of the EFs they supposedly measure. Alternatively, the two tasks might recruit mostly the same dopaminergic mechanisms, but the DA level for optimal performance might vary between tasks. In any case, our unexpected findings of differential effects of sulpiride on performance in the two tasks should therefore be regarded as preliminary, but hopefully give rise to further investigation.

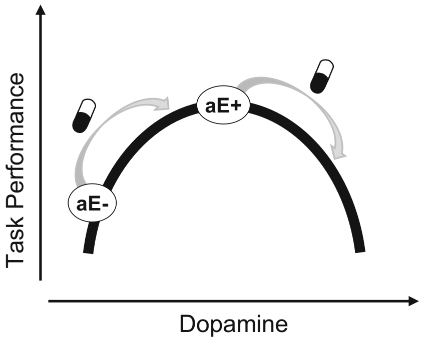

Fig. 2 Inverted-U shaped model depicts the relationship between baseline dopamine and performance in executive functioning tasks for individuals low (aE-) or high (aE+) in agentic extraversion. The arrows illustrate how the association between agentic extraversion and task performance is attenuated (or even reversed) under sulpiride

Relationship Between the 3-back Task and the Switching Task

The pattern of significant interaction effects of condition and agentic extraversion in both tasks, and their attenuation after the inclusion of the respective other EF task performance measure, suggests that these interaction effects can be at least partly ascribed to shared task variance. This refers either to the unity of EF tasks, i.e., a shared executive component which is relevant for both tasks, or to task-impurity, i.e., other systematic variance of processes needed for the task, for example visual processing, number/letter processing or manual motor skills. As the switching task is based on difference scores, which would theoretically alleviate task-impurity (Kessler et al., 2017), we suggest that shared variance might at least partly be ascribed to the unity of EFs. From this would follow that agentic extraversion might be associated with a unitary component of EF variance common to most EF tasks rather than being separately associated with specific EFs. This has the more general implication that future research on personality-EF associations should be cautious with statements of specific associations if only one EF task was investigated.

The placebo group's positive association between accuracy in the 3-back task and flexibility in the switching task seemed to be driven mainly by the switching task's learned irrelevance condition. Higher 3-back accuracy was clearly associated with higher switch costs in the learned irrelevance condition (assumed to measure distractibility), while there was no association for the perseverance condition (assumed to measure stickiness of no longer relevant representations). This may be taken to indicate that stickiness might be less important in the 3-back task, whereas individual differences in the updating threshold are relevant for both tasks. A lower threshold might be advantageous for 3-back accuracy, as the 3-back task requires rapid updating of new information, but disadvantageous for switch costs in the learned irrelevance condition, as this condition is (partly) constructed to capture distractibility due to a low updating threshold. However, because the interpretation of the association between 3-back accuracy and switch costs in the learned irrelevance condition is complicated by its unexpected sensitivity to sulpiride, it should be regarded as preliminary.

Limitations

Some methodological limitations have to be considered. The homogeneous sample of healthy young females who all were in a heterosexual partnership and took hormonal contraception was chosen to minimize variance but limits the generalizability of our results. Statistical power was sufficient for general cognitive effects but might have not been optimal for the investigation of associations between task performance and personality as prior studies might have overestimated effect sizes. Furthermore, we did not control for the intake method of hormonal contraception or for the amount of estradiol derivates, which varies among contraceptive medications. Although all participants received the same amount of sulpiride (200 mg), it seems unlikely that a variation in the relative dose per kilogram body weight was associated with performance differences because we did not find a significant effect of body weight as a covariate. However, prior studies reported an inverted-U relationship between DA and working memory functions (Cools & D'Esposito, 2011), as well as an inverted-U relationship between extraversion and EEG theta activity (Chavanon et al., 2013), which were both demonstrated with the help of varying doses of DA agonists and antagonists. A systematic investigation of (non-linear) dose-dependent effects of DA agonists and antagonists could provide further insight into their effects on the relationship between extraversion and EFs. Because the plasma concentration of sulpiride further varies over time with a peak after 1 to 6 hours (Mauri et al., 1996), there is a small possibility that plasma concentration varied systematically between the two tasks, which were presented in a fixed order after one another. We assume that this had little impact on performance because, relative to the length of the tasks, the variation in peak plasma concentration is quite large.

Additionally, the behavioral patterns we found do not necessarily have to be directly associated with altered striatal DA or the balance between prefrontal and striatal DA. The current pharmacological alteration of striatal DA might have various complex effects within the corticostriatal loop, which can indirectly affect other systems. EFs also are not exclusively regulated by DA but are partly also sensitive to noradrenergic manipulations (Arnsten, 2011). A more detailed understanding of the neural areas and processes regulating task performance could be facilitated with the help of neuroimaging during task completion and/or with computational models (Chatham et al., 2011; Herd et al., 2014). The latter could be fruitful for a deeper understanding of the neurobiological basis of extraversion by simulating individual differences within these models.

Unclarity regarding construct validity and reliability, especially of the switching task, also needs to be considered. First, despite repeated use of the switching task in (mostly) cognitive research (Müller, Dreisbach, Brocke, et al., 2007; Müller, Dreisbach, Goschke, et al., 2007) to our knowledge we are the first to report reliability estimates for the switching task. It should be noted that low reliability does not necessarily equal high measurement variance but can also be caused by low between-subject variability. Because experimental effects across all individuals are more pronounced when between-subject variability is low, a low reliability might even be seen as an unintended prerequisite of a successful cognitive task, which complicates the translation to the investigation of individual differences (Hedge et al., 2018). In any case, the low reliability observed here clearly limits the conclusions to be drawn from measured individual differences in the switching task and future studies using indicators for shifting with higher psychometric quality are needed to confirm the current observations. It might be a fruitful approach to maximize between-subject variability and to minimize measurement variance by applying more frequent switches and/or more task blocks. Between-subject variability could be increased by making the task more demanding, e.g., with a latency criterion, in order to have higher error rates.

Second, while the majority of studies on the n-back task report accuracy measures (Karr et al., 2018), a prior study reporting an association with extraversion found effects in reaction times but not in accuracy (Wacker et al., 2006). Taken together, it would be interesting to investigate whether the tasks and their respective measures used here actually measure the same constructs as other EF tasks and their respective measures. Investigating the interaction of extraversion and a dopaminergic manipulation with latent EFs, e.g., within the unity/diversity framework (Friedman & Miyake, 2017), would help to clarify matters of validity and task impurity.

Conclusions

In this study, our goal was to elucidate the link between EFs and agentic extraversion by using more than one EF task to compare shared and task-specific variance in EF tasks. We found agentic extraversion in the placebo condition to be associated with performance in both the 3-back task and the switching task. Furthermore, the results from our additional analyses were likewise compatible with the interpretation that the association between each individual task and agentic extraversion can at least partly be ascribed to shared variance among the two tasks. Thus, previous investigations on extraversion-EF associations may have overestimated their specificity to a certain EF, and future research may consider the unity of EFs, as well as task impurity of EF tasks, for the investigation of third-variable associations. Furthermore, we found the extraversion-EF associations to be sensitive to a dopaminergic manipulation, which extends prior findings indicating a functional interplay or overlap of the neuronal systems regulating EFs and agentic extraversion. Future pharmacological studies using more than two EF tasks with satisfactory reliability in conjunction with a latent variable approach in large samples are necessary to bolster the current conclusions and to further connect the fields of personality research, cognitive psychology, and neuroscience.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13415-021-00887-9 .

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References

Arnsten, A. F. (2011). Catecholamine influences on dorsolateral prefrontal cortical networks. *Biological Psychiatry, 69*(12), e89–e99. https://doi.org/10.1016/j.biopsych.2011.01.027

Baik, S., Yoon, H. S., Kim, S. E., & Kim, S. H. (2012). Extraversion and striatal dopaminergic receptor availability in young adults. *NeuroReport*, *23*(4), 251–254. https://doi.org/10.1097/WNR.0b013e3283507533

Berse, T., Barenberg, J., Urban, V., & Dutke, S. (2014). Agentic extraversion moderates the effect of physical exercise on executive shifting performance. *Journal of Research in Personality*, *52*, 37–41. https://doi.org/10.1016/j.jrp.2014.06.007

Boot, N., Baas, M., van Gaal, S., Cools, R., & Dreu, C. K. W. de (2017). Creative cognition and dopaminergic modulation of fronto-striatal networks: Integrative review and research agenda. *Neuroscience and Biobehavioral Reviews*, *78*, 13–23. https://doi.org/10.1016/j.neubiorev.2017.04.007

Burgdorf, C., Rinn, C., & Stemmler, G. (2015). Effects of personality on the opioidergic modulation of the emotion warmth-liking. *Journal of Comparative Neurology*, *524*(8), 1712–1726. https://doi.org/10.1002/cne.23847

Campbell, A. M., Davalos, D. B., McCabe, D. P., & Troup, L. J. (2011). Executive functions and extraversion. *Personality and Individual Differences*, *51*(6), 720–725. https://doi.org/10.1016/j.paid.2011.06.018

Cattell, R., & Weiß, R. (1971). *Grundintelligenztest Skala 3 (CFT3)*. Hogrefe.

Chatham, C. H., Herd, S. A., Brant, A. M., Hazy, T. E., Miyake, A., O'Reilly, R., & Friedman, N. P. (2011). From an Executive Network to Executive Control: A Computational Model of the n-back Task. *Journal of Cognitive Neuroscience*, *23*(11), 3598–3619. https://doi.org/10.1162/jocn_a_00047

Chavanon, M.-L., Wacker, J., & Stemmler, G. (2013). Paradoxical dopaminergic drug effects in extraversion: dose- and time-dependent effects of sulpiride on EEG theta activity. *Frontiers in Human Neuroscience*, *7*, 1–15. https://doi.org/10.3389/fnhum.2013.00117

Chiew, K. S., & Braver, T. S. (2017). Context processing and cognitive control. In *The Wiley Handbook of Cognitive Control* (pp. 143–166). https://doi.org/10.1002/9781118920497.ch9

Cools, R. (2016). The costs and benefits of brain dopamine for cognitive control. *Wiley Interdisciplinary Reviews. Cognitive Science*, *7*(5), 317–329. https://doi.org/10.1002/wcs.1401

Cools, R., & D'Esposito, M. (2011). Inverted-U-shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry*, *69*(12), e113-e125. https://doi.org/10.1016/j.biopsych.2011.03.028

Cools, R., Froböse, M., Aarts, E., & Hofmans, L. (2019). Dopamine and the motivation of cognitive control. *Handbook of Clinical Neurology*, *163*, 123–143. https://doi.org/10.1016/B978-0-12-804281-6.00007-0

Cools, R., Sheridan, M., Jacobs, E., & D'Esposito, M. (2007). Impulsive personality predicts dopamine-dependent changes in frontostriatal activity during component processes of working memory. *The Journal of Neuroscience*, *27*(20), 5506–5514. https://doi.org/10.1523/JNEUROSCI.0601-07.2007

Depue, R. A., & Collins, P. F. (1999). Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences*, *22*(3), 491–569. https://doi.org/10.1017/S0140525X99002046

Doll, B. B., & Frank, M. J. (2009). The basal ganglia in reward and decision making. In J.-C. Dreher & L. Tremblay (Eds.), *Handbook of reward and decision making* (pp. 399–425). Academic Press. https://doi.org/10.1016/B978-0-12-374620-7.00019-4

Dreisbach, G. (2006). How positive affect modulates cognitive control: The costs and benefits of reduced maintenance capability. *Brain and Cognition*, *60*(1), 11–19. https://doi.org/10.1016/j.bandc.2005.08.003

Dreisbach, G., & Fröber, K. (2019). On How to Be Flexible (or Not): Modulation of the Stability-Flexibility Balance. *Current Directions in Psychological Science*, *28*(1), 3–9. https://doi.org/10.1177/0963721418800030

Dreisbach, G., & Goschke, T. (2004). How positive affect modulates cognitive control: reduced perseveration at the cost of increased distractibility. *Journal of Experimental Psychology: Learning Memory and Cognition*, *30*(2), 343–353. https://doi.org/10.1037/0278-7393.30.2.343

Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K.-P., & Brocke, B. (2005). Dopamine and Cognitive Control: The Influence of Spontaneous Eyeblink Rate and Dopamine Gene Polymorphisms on Perseveration and Distractibility. *Behavioral Neuroscience*, *119*(2), 483–490. https://doi.org/10.1037/0735-7044.119.2.483

Ecker, U. K., Lewandowsky, S., Oberauer, K., & Chee, A. E. (2010). The Components of Working Memory Updating: An Experimental Decomposition and Individual Differences. *Journal of Experimental Psychology: Learning Memory and Cognition*, *36*(1), 170–189. https://doi.org/10.1037/a0017891

Fallon, S. J., Smulders, K., Esselink, R. A., van de Warrenburg, Bart P., Bloem, B. R., & Cools, R. (2015). Differential optimal dopamine levels for set-shifting and working memory in Parkinson's disease. *Neuropsychologia*, *77*, 42–51. https://doi.org/10.1016/j.neuropsychologia.2015.07.031

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Floresco, S. B. (2013). Prefrontal dopamine and behavioral flexibility: Shifting from an "inverted-U" toward a family of functions. *Frontiers in Neuroscience*, *7*(62), 1–12. https://doi.org/10.3389/fnins.2013.00062

Friedman, N. P., & Miyake, A. (2017). Unity and Diversity of Executive Functions: Individual Differences as a Window on Cognitive

Structure. *Cortex*, *86*, 186–204. https://doi.org/10.1126/science.1249098.Sleep

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., Defries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, *17*(2), 172–179. https://doi.org/10.1111/j.1467-9280.2006.01681.x

Goschke, T., & Bolte, A. (2014). Emotional modulation of control dilemmas: The role of positive affect, reward, and dopamine in cognitive stability and flexibility. *Neuropsychologia*, *62*, 403–423. https://doi.org/10.1016/j.neuropsychologia.2014.07.015

Gray, J. R., & Braver, T. S. (2002). Personality predicts working-memory-related activation in the caudal anterior cingulate cortex. *Cognitive, Affective, & Behavioral Neuroscience*, *2*(1), 64–75. https://doi.org/10.3758/CABN.2.1.64

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods*, *50*(3), 1166–1186. https://doi.org/10.3758/s13428-017-0935-1

Heitz, R. P. (2014). The speed-accuracy tradeoff: History, physiology, methodology, and behavior. *Frontiers in Neuroscience*, *8*, 150. https://doi.org/10.3389/fnins.2014.00150

Herd, S. A., O´Reilly, R. C., Hazy, T. E., Chatham, C. H., Brant, A. M., & Friedman, N. P. (2014). A neural network model of individual differences in task switching abilities. *Neuropsychologia*, *62*, 375–389. https://doi.org/10.1016/j.neuropsychologia.2014.04.014

Jongkees, B. J., & Colzato, L. S. (2016). Spontaneous eye blink rate as predictor of dopamine-related cognitive function—A review. *Neuroscience and Biobehavioral Reviews*, *71*, 58–82. https://doi.org/10.1016/j.neubiorev.2016.08.020

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *17*(11), 4302–4311. https://doi.org/10.1523/JNEUROSCI.17-11-04302.1997

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. *Psychological Bulletin*, *144*(11), 1147–1185. https://doi.org/10.1037/bul0000160

Kessler, Y., Baruchin, L. J., & Bouhsira-Sabag, A. (2017). Working memory updating occurs independently of the need to maintain task-context: accounting for triggering updating in the AX-CPT paradigm. *Psychological Research*, *81*(1), 191–203. https://doi.org/10.1007/s00426-015-0717-2

Kimberg, D. Y., D'Esposito, M., & Farah, M. J. (1997). Effects of bromocriptine on human subjects depend on working memory capacity. *NeuroReport*, *8*(16), 3581–3585. https://doi.org/10.1097/00001756-199711100-00032

Kuroki, T., Meltzer, H. Y., & Ichikawa, J. (1999). Effects of antipsychotic drugs on extracellular dopamine levels in rat medial prefrontal cortex and nucleus accumbens. *The Journal of Pharmacology and Experimental Therapeutics*, *288*(2), 774–781.

Lai, H., Wang, S., Zhao, Y., Zhang, L., Yang, C., & Gong, Q. (2019). Brain gray matter correlates of extraversion: A systematic review and meta-analysis of voxel-based morphometry studies. *Human Brain Mapping*, *40*(14), 4038–4057. https://doi.org/10.1002/hbm.24684

Lemire-Rodger, S., Lam, J., Viviano, J. D., Stevens, W. D., Spreng, R. N., & Turner, G. R. (2019). Inhibit, switch, and update: A within-subject fMRI investigation of executive control. *Neuropsychologia*, *132*, 1–12. https://doi.org/10.1016/j.neuropsychologia.2019.107134

Li, M., Wei, D., Yang, W., Zhang, J., & Qiu, J. (2019). Neuroanatomical correlates of extraversion. *NeuroReport*, *30*(14), 953–959. https://doi.org/10.1097/WNR.0000000000001306

Lieberman, M. D., & Rosenthal, R. (2001). Why introverts can't always tell who likes them: multitasking and nonverbal decoding. *Journal of Personality and Social Psychology*, *80*(2), 294. https://doi.org/10.1037/0022-3514.80.2.294

Luciana, M., Depue, R. A., Arbisi, P., & Leon, A. (1992). Facilitation of Working Memory in Humans by a D 2 Dopamine Receptor Agonist. *Journal of Cognitive Neuroscience*, *4*(1), 58–68. https://doi.org/10.1162/jocn.1992.4.1.58

Mauri, M. C., Bravin, S., Bitetto, A., Rudelli, R., & Invernizzi, G. (1996). A risk-benefit assessment of sulpiride in the treatment of schizophrenia. *Drug Safety*, *14*(5), 288–298. https://doi.org/10.2165/00002018-199614050-00003

Miyake, A., & Friedman, N. P. (2012). The Nature and Organisation of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*(3), 134–140. https://doi.org/10.1016/S1364-6613(03)00028-7

Morrone-Strupinsky, J. V., & Depue, R. A. (2004). Differential relation of two distinct, film-induced positive emotional states to affiliative and agentic extraversion. *Personality and Individual Differences*, *36*(5), 1109–1126. https://doi.org/10.1016/S0191-8869(03)00204-6

Mueller, E. M., Burgdorf, C., Chavanon, M.-L., Schweiger, D., Hennig, J., Wacker, J., & Stemmler, G. (2014). The COMT Val158Met polymorphism regulates the effect of a dopamine antagonist on the feedback-related negativity. *Psychophysiology*, *51*(8), 805–809. https://doi.org/10.1111/psyp.12226

Mueller, E. M., Burgdorf, C., Chavanon, M.-L., Schweiger, D., Wacker, J., & Stemmler, G. (2014). Dopamine modulates frontomedial failure processing of agentic introverts versus extraverts in incentive contexts. *Cognitive, Affective and Behavioral Neuroscience*, *14*(2), 756–768. https://doi.org/10.3758/s13415-013-0228-9

Müller, J., Dreisbach, G., Brocke, B., Lesch, K.-P., Strobel, A., & Goschke, T. (2007). Dopamine and cognitive control: The influence of spontaneous eyeblink rate, DRD4 exon III polymorphism and gender on flexibility in set-shifting. *Brain Research*, *1131*(1), 155–162. https://doi.org/10.1016/j.brainres.2006.11.002

Müller, J., Dreisbach, G., Goschke, T., Hensch, T., Lesch, K.-P., & Brocke, B. (2007). Dopamine and cognitive control: The prospect of monetary gains influences the balance between flexibility and stability in a set-shifting paradigm. *European Journal of Neuroscience*, *26*(12), 3661–3668. https://doi.org/10.1111/j.1460-9568.2007.05949.x

Murdock, K. W., Oddi, K. B., & Bridgett, D. J. (2013). Cognitive Correlates of Personality: Links Between Executive Functioning and the Big Five Personality Traits. *Journal of Individual Differences*, *34*(2), 97–104. https://doi.org/10.1027/1614-0001/a000104

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective & Behavioral Neuroscience*, *12*(2), 241–268. https://doi.org/10.3758/s13415-011-0083-5

Ostendorf, F., & Angleitner, A. (2004). *NEO-Persönlichkeitsinventar nach Costa und McCrae: NEO-PI-R ; Manual Revidierte Fassung*. Göttingen: Hogrefe.

Reineberg, A. E., Gustavson, D. E., Benca, C., Banich, M. T., & Friedman, N. P. (2018). The Relationship Between Resting State Network Connectivity and Individual Differences in Executive Functions. *Frontiers in Psychology*, *9*, 1600. https://doi.org/10.3389/fpsyg.2018.01600

Rencher, A. C. (2002). *Methods of multivariate analysis* (2. ed.). Wiley-Interscience. https://doi.org/10.1002/0471271357

Schweiger, D., Stemmler, G., Burgdorf, C., & Wacker, J. (2013). Opioid receptor blockade and warmth-liking: Effects on interpersonal trust and frontal asymmetry. *Social Cognitive and Affective Neuroscience*, *9*(10), 1608–1615. https://doi.org/10.1093/scan/nst152

Sigala, S., Rizzonelli, P., Zanelli, E., Forgione, A., Missale, C., & Spano, P. (1991). Low doses of I-sulpiride down-regulate striatal and cortical dopamine receptors and β-adrenoceptors. *European Journal of Pharmacology*, *199*(2), 247–253. https://doi.org/10.1016/0014-2999(91)90465-3

Smith, E. E., & Jonides, J. (1997). Working memory: A view from neuroimaging. *Cognitive Psychology*, *33*(1), 5–42. https://doi.org/10.1006/cogp.1997.0658

Szmalec, A., Verbruggen, F., Vandierendonck, A., & Kemps, E. (2011). Control of interference during working memory updating. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(1), 137–151. https://doi.org/10.1037/a0020365

Tellegen, A., & Waller, N. G. (2008). Exploring personality through test construction: Development of the Multidimensional Personality Questionnaire. In G. J. Boyle, G. Matthews, & D. H. Saklofske (Eds.), *The SAGE handbook of personality theory and assessment, Vol. 2. Personality measurement and testing* (p. 261–292). Sage Publications, Inc. https://doi.org/10.4135/9781849200479.n13

Vaughan, R. S., & Edwards, E. J. (2020). Executive function and personality: The moderating role of athletic expertise. *Personality and Individual Differences*, *161*, 1–7. https://doi.org/10.1016/j.paid.2020.109973

Wacker, J. (2018). Effects of positive emotion, extraversion, and dopamine on cognitive stability-flexibility and frontal EEG asymmetry. *Psychophysiology*, *55(1)*, 1–16. https://doi.org/10.1111/psyp.12727

Wacker, J., Chavanon, M.-L., & Stemmler, G. (2006). Investigating the dopaminergic basis of extraversion in humans: A multilevel approach. *Journal of Personality and Social Psychology*, *91*(1), 171–187. https://doi.org/10.1037/0022-3514.91.1.171

Westbrook, A., van den Bosch, R., Määttä, J. I., Hofmans, L., Papadopetraki, D., Cools, R., & Frank, M. J. (2020). Dopamine promotes cognitive effort by biasing the benefits versus costs of cognitive work. *Science*, *367*(6484), 1362–1366. https://doi.org/10.1126/science.aaz5891

Yee, D. M., & Braver, T. S. (2018). Interactions of motivation and cognitive control. *Current Opinion in Behavioral Sciences*, *19*, 83–90. https://doi.org/10.1016/j.cobeha.2017.11.009

Appendix B

Herrmann, W. & Wacker, J. (in press). Executive Functions Neither Associated with Agentic Extraversion nor Sensitive to the Dopamine D2 Blocker Sulpiride in a Preregistered Study. *Personality Science*.

PS Official Paper Template
(FOR REVIEW)

Manuscript Title: Executive Functions Neither Associated with Agentic Extraversion nor Sensitive to the Dopamine D2 Blocker Sulpiride in a Preregistered Study

Running Head: EXTRAVERSION AND EXECUTIVE FUNCTIONS

Version Date: 16.02.2022

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Wiebke Herrmann; University of Hamburg; Hamburg; Germany
Jan Wacker; University of Hamburg; Hamburg; Germany

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English Abstract

Max. 150 words; no formatting – plain text only

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.

English Keywords

Max. 8 keywords (all in lower-case, except for names), delimited by semicolons

stability-flexibility; dopamine; extraversion; executive functions

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OPTIONAL: Abstract in another language

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Abstract goes here

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keyword; keyword; keyword; keyword; keyword; keyword; keyword; keyword

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Key Insights

3-5 bullet points as summaries, with max. 10 words each

- 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.

Relevance Statement

Max. 250 characters, including spaces
Please do not just summarize the paper, but highlight its relevance, interestingness, and unique merits.

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.

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A non-technical summary for a lay audience aims to increase the dissemination of your findings beyond disciplines and academia more generally. It should avoid jargon as much as possible and communicate main findings and their practical and policy-related implications in clear and simple language.
Please use the following sub-headings (that can be modified for theoretical and review articles) to structure the non-technical summary:

1. What is the study's background?
2. Why was this study done?
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4. What do these findings mean?

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Type	URL
Pre-registration	https://osf.io/eazuh and https://osf.io/phr4g
Data	The previous DOI for all material (https://doi.org/10.7802/2329) remains online as version 1.0, the updated version is named 1.1 (https://doi.org/10.7802/2374). The data remain unchanged, we only added minor analyses in one analysis script.
Codebook	https://doi.org/10.7802/2374
Documents, stimuli, images, etc.	
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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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Author note

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. We have no conflict of interest to disclose. 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). This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The authors contributed as follows: As principal investigator, JW was responsible for planning and overseeing the project, and reviewed data analysis, interpretation, and the writing process of the manuscript. WH collected parts of the data, analyzed and interpreted the data, created the open material, and wrote the manuscript.

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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

Appendix B

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

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 et al., 2006; Wacker, 2018).

Whereas previous studies on extraversion-related differences in dopaminergic drug effects on EF 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 (https://osf.io/eazuh). 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).

Methods

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 $f = 0.2$ ($\alpha =$

.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).

The 3-back task requires participants to continuously buffer new information with the goal to measure working memory updating (Herrmann & Wacker, 2021). For better comparison 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 to 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 (https://osf.io/eazuh), and a list of all measures (https://osf.io/phr4g) 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 under https://doi.org/10.7802/2374. 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).

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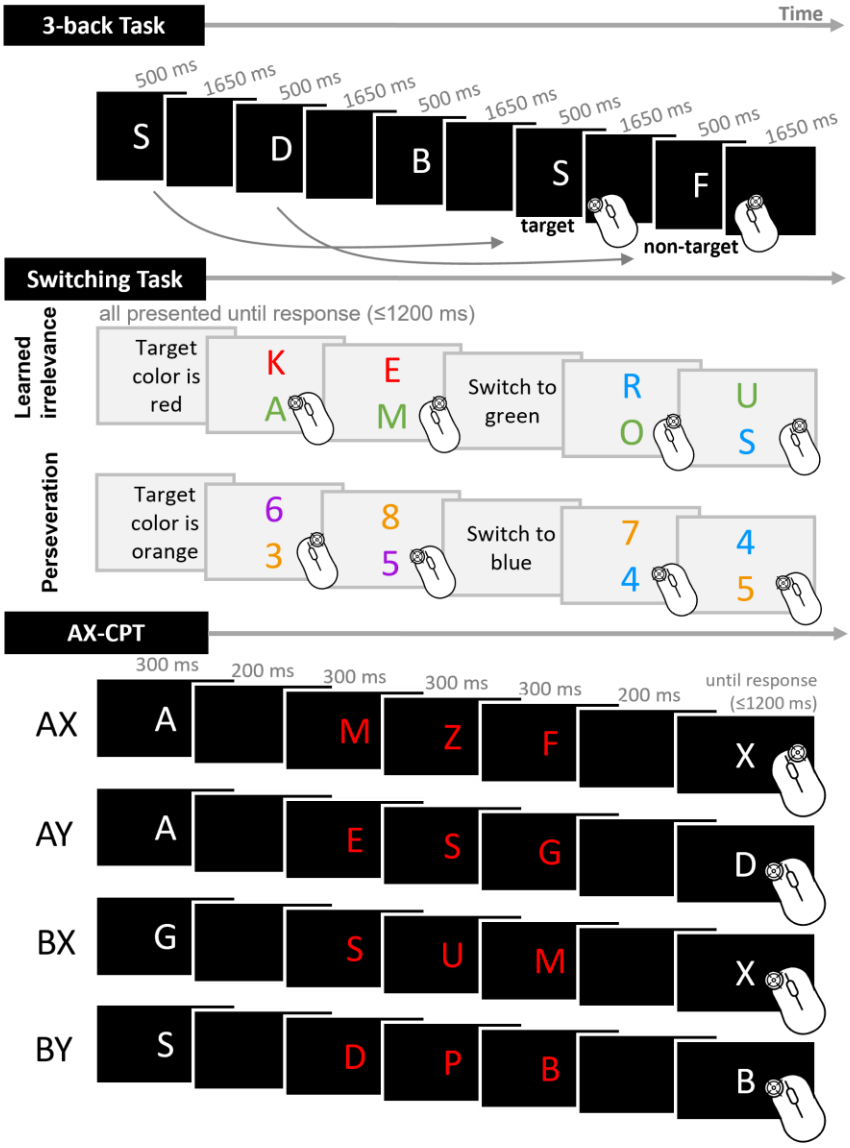
Figure 1

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 of 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.

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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 (χ^2 (1) = 0.02, $p = 0.89$) and individual confidence in the substance condition guess ($\chi^2(3) = 2.22$, $p = 0.53$).

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 $\alpha = .83$; post-switch: Cronbach´s $\alpha = .81$), but very low for difference scores (switch costs: Cronbach´s $\alpha = .23$, switch cost difference between switching conditions: Cronbach´s $\alpha = .27$). 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 ($r(196) =$

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Table 1

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

Variable	Placebo		Sulpiride				Total	
	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.

.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 2) although this effect should be interpreted with caution as it was not predicted.

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Table 2

Linear (Mixed) Models for Task Performance.

Effect	*B*	*SE*	*95% CI*		*p*
			LL	UL	
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
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.

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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 (https://doi.org/10.7802/2374). 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 *p*s > .10 for uncorrected highest-order effects involving openness; *p*s > .90 for all NEO scales and their interactions when controlling the family-wise error rate by Holm-correcting for all statistical tests per task).

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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, 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. 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.

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

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 et al., 2006; Wacker, 2018). 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).

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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 et al., 2006; Wacker, 2018), 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 of 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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References

Arendasy, M., Hornke, L. F., Sommer, M., Wagner-Menghin, M., Gittler, G., Häusler, J., Bognar, B., & Wenzl, M. (2012). *Intelligenz-Struktur-Batterie (INSBAT)* (27th ed.). Schuhfried GmbH.

Ashton, M. C., Lee, K., Vernon, P. A., & Jang, K. L. (2000). Fluid Intelligence, Crystallized Intelligence, and the Openness/Intellect Factor. *Journal of Research in Personality*, *34*(2), 198–207. https://doi.org/10.1006/jrpe.1999.2276

Baik, S., Yoon, H. S., Kim, S. E., & Kim, S. H. (2012). Extraversion and striatal dopaminergic receptor availability in young adults. *NeuroReport*, *23*(4), 251–254. https://doi.org/10.1097/WNR.0b013e3283507533

Barr, D. J. (2013). Random effects structure for testing interactions in linear mixed-effects models. *Frontiers in Psychology*, *4*, 328. https://doi.org/10.3389/fpsyg.2013.00328

Campbell, A. M., Davalos, D. B., Mccabe, D. P., & Troup, L. J. (2011). Executive functions and extraversion. *Personality and Individual Differences*, *51*(6), 720–725. https://doi.org/10.1016/j.paid.2011.06.018

Chatham, C. H., Herd, S. A., Brant, A. M., Hazy, T. E., Miyake, A., O'Reilly, R., & Friedman, N. P. (2011). From an Executive Network to Executive Control: A Computational Model of the n-back Task. *Journal of Cognitive Neuroscience*, *23*(11), 3598–3619. https://doi.org/10.1162/jocn_a_00047

Chavanon, M.-L., Wacker, J., Leue, A., & Stemmler, G. (2007). Evidence for a dopaminergic link between working memory and agentic extraversion: An analysis of load-related changes in EEG alpha 1 activity. *Biological Psychology*, *74*(1), 46–59. https://doi.org/10.1016/j.biopsycho.2006.07.001

Chiew, K. S., & Braver, T. S. (2014). Dissociable influences of reward motivation and positive emotion on cognitive control. *Cognitive, Affective & Behavioral Neuroscience*, *14*(2), 509–529. https://doi.org/10.3758/s13415-014-0280-0

Cools, R. (2019). Chemistry of the Adaptive Mind: Lessons from Dopamine. *Neuron*, *104*(1), 113–131. https://doi.org/10.1016/j.neuron.2019.09.035

Costa, P. T., & McCrae, R. R. (2010). *The NEO Personality Inventory: 3*. Psychological Assessment Resources.

Dang, C.-P., Braeken, J., Colom, R., Ferrer, E., & Liu, C. (2014). Why is working memory related to intelligence? Different contributions from storage and processing. *Memory (Hove, England)*, *22*(4), 426–441. https://doi.org/10.1080/09658211.2013.797471

Depue, R. A., & Collins, P. F. (1999). Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences*, *22*(3), 491–569. https://doi.org/10.1017/S0140525X99002046

DeYoung, C. G. (2013). The neuromodulator of exploration: A unifying theory of the role of dopamine in personality. *Frontiers in Human Neuroscience*, *7*, 762. https://doi.org/10.3389/fnhum.2013.00762

Dreisbach, G. (2006). How positive affect modulates cognitive control: The costs and benefits of reduced maintenance capability. *Brain and Cognition*, *60*(1), 11–19. https://doi.org/10.1016/j.bandc.2005.08.003

Fallon, S. J., Kienast, A., Muhammed, K., Ang, Y.-S., Manohar, S. G., & Husain, M. (2019). Dopamine D2 receptor stimulation modulates the balance between ignoring and updating according to baseline working memory ability. *Journal of Psychopharmacology (Oxford, England)*, *33*(10), 1254–1263. https://doi.org/10.1177/0269881119872190

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Appendix B

Friedman, N. P., & Miyake, A. (2017). Unity and Diversity of Executive Functions: Individual Differences as a Window on Cognitive Structure. *Cortex*, *86*, 186–204. https://doi.org/10.1126/science.1249098.Sleep

Gonthier, C., Macnamara, B. N., Chow, M., Conway, A. R. A., & Braver, T. S. (2016). Inducing Proactive Control Shifts in the AX-CPT. *Frontiers in Psychology*, *7*, 1822. https://doi.org/10.3389/fpsyg.2016.01822

Hermes, M., Hagemann, D., Naumann, E., & Walter, C. (2011). Extraversion and its positive emotional core-further evidence from neuroscience. *Emotion*, *11*(2), 367–378. https://doi.org/10.1037/a0021550

Herrmann, W., & Wacker, J. (2021). The Selective Dopamine D2 Blocker Sulpiride Modulates the Relationship Between Agentic Extraversion and Executive Functions. *Cognitive, Affective & Behavioral Neuroscience.* https://doi.org/10.3758/s13415-021-00887-9

Käckenmester, W., Bott, A., & Wacker, J. (2019). Openness to experience predicts dopamine effects on divergent thinking. *Personality Neuroscience*, *2.* https://doi.org/10.1017/pen.2019.3

Lai, H., Wang, S., Zhao, Y., Zhang, L., Yang, C., & Gong, Q. (2019). Brain gray matter correlates of extraversion: A systematic review and meta-analysis of voxel-based morphometry studies. *Human Brain Mapping*, *40*(14), 4038–4057. https://doi.org/10.1002/hbm.24684

Lieberman, M. D., & Rosenthal, R. (2001). Why introverts can’t always tell who likes them: multitasking and nonverbal decoding. *Journal of Personality and Social Psychology*, *80*(2), 294. https://doi.org/10.1037/0022-3514.80.2.294

Macmillan, N. A., & Creelman, C. D. (1990). Response bias: Characteristics of detection theory, threshold theory, and “nonparametric” indexes. *Psychological Bulletin*, *107*(3), 401–413. https://doi.org/10.1037/0033-2909.107.3.401

Margraf, J., Cwik, J. C., Pflug, V., & Schneider, S. (2017). Strukturierte klinische Interviews zur Erfassung psychischer Störungen über die Lebensspanne. *Zeitschrift Für Klinische Psychologie Und Psychotherapie*, *46*(3), 176–186. https://doi.org/10.1026/1616-3443/a000430

Mauri, M. C., Bravin, S., Bitetto, A., Rudelli, R., & Invernizzi, G. (1996). A risk-benefit assessment of sulpiride in the treatment of schizophrenia. *Drug Safety*, *14*(5), 288–298. https://doi.org/10.2165/00002018-199614050-00003

Mehta, M. A., Montgomery, A. J., Kitamura, Y., & Grasby, P. M. (2008). Dopamine D2 receptor occupancy levels of acute sulpiride challenges that produce working memory and learning impairments in healthy volunteers. *Psychopharmacology*, *196*(1), 157–165. https://doi.org/10.1007/s00213-007-0947-0

Mehta, M. A., Sahakian, B. J., McKenna, P. J., & Robbins, T. W. (1999). Systemic sulpiride in young adult volunteers simulates the profile of cognitive deficits in Parkinson’s disease. *Psychopharmacology*, *146*(2), 162–174. https://doi.org/10.1007/s002130051102

Müller, J., Dreisbach, G., Brocke, B., Lesch, K.-P., Strobel, A., & Goschke, T. (2007). Dopamine and cognitive control: The influence of spontaneous eyeblink rate, DRD4 exon III polymorphism and gender on flexibility in set-shifting. *Brain Research*, *1131*(1), 155–162. https://doi.org/10.1016/j.brainres.2006.11.002

Nijstad, B. A., Dreu, C. K. W. de, Rietzschel, E. F., & Baas, M. (2010). The dual pathway to creativity model: Creative ideation as a function of flexibility and persistence. *European Review of Social Psychology*, *21*(1), 34–77. https://doi.org/10.1080/10463281003765323

Ohmann, H. A., Kuper, N., & Wacker, J. (2020). A low dosage of the dopamine D2-receptor antagonist sulpiride affects effort allocation for reward regardless of trait extraversion. *Personality Neuroscience*, *3*. https://doi.org/10.1017/pen.2020.7

Paul, K., Pourtois, G., van Steenbergen, H., Gable, P., & Dreisbach, G. (2021). Finding a balance: modulatory effects of positive affect on attentional and cognitive control. *Current Opinion in Behavioral Sciences*, *39*, 136–141. https://doi.org/10.1016/j.cobeha.2021.03.002

Schmitz, F., & Voss, A. (2012). Decomposing task-switching costs with the diffusion model. *Journal of Experimental Psychology. Human Perception and Performance*, *38*(1), 222–250. https://doi.org/10.1037/a0026003

Smillie, L. D., Bennett, D., Tan, N. P., Sutcliffe, K., Fayn, K., Bode, S., & Wacker, J. (2021). Does openness/intellect predict sensitivity to the reward value of information? *Cognitive, Affective & Behavioral Neuroscience*, *21*(5), 993–1009. https://doi.org/10.3758/s13415-021-00900-1

Trafimow, D. (2015). A defense against the alleged unreliability of difference scores. *Cogent Mathematics*, *2*(1), 3. https://doi.org/10.1080/23311835.2015.1064626

Wacker, J. (2018). Effects of positive emotion, extraversion, and dopamine on cognitive stability-flexibility and frontal EEG asymmetry. *Psychophysiology*, *55(1)*, 1–16. https://doi.org/10.1111/psyp.12727

Wacker, J., Chavanon, M.-L., & Stemmler, G. (2006). Investigating the dopaminergic basis of extraversion in humans: A multilevel approach. *Journal of Personality and Social Psychology*, *91*(1), 171–187. https://doi.org/10.1037/0022-3514.91.1.171

Wacker, J., & Smillie, L. D. (2015). Trait Extraversion and Dopamine Function. *Social and Personality Psychology Compass*, *9*(6), 225–238. https://doi.org/10.1111/spc3.12175

Westbrook, A., Frank, M. J., & Cools, R. (2021). A mosaic of cost-benefit control over cortico-striatal circuitry. *Trends in Cognitive Sciences*, *25*(8), 710–721. https://doi.org/10.1016/j.tics.2021.04.007

Appendix C

Herrmann, W. & Wacker, J. Executive Functions are Associated with Trait (but not State) Extraversion. Submitted to *European Journal of Personality*.

Executive Functions are Associated with Trait (but not State) Extraversion

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Manuscript Keywords:	extraversion, executive functions, stability-flexibility, positive affect, eye-blink rate

Executive Functions are Associated with Trait (but not State) Extraversion

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The current analysis (https://osf.io/jcuq3/?view_only=e941f9154f6a4747b39db2fb5bfc8ed0) was registered on the Open Science Framework after the data were collected. Raw and aggregated data, and a supplementary R Markdown analysis are available under https://osf.io/gr2bt/?view_only=564a9304fd02473d898612fb06edfdc5. We have no conflict of interest to disclose. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Abstract

Intentionally acting extraverted reliably increases positive affect (PA). As both trait extraversion and PA have further been connected to executive functions (EFs), especially stability-flexibility, we experimentally manipulated extraverted states (*N*=108) via acting instructions for group discussions with balanced conditions (enacted extraversion/introversion/control) to investigate effects on EFs. We expected acting condition to affect (1) state extraversion and PA in self- and informant-report questionnaires, (2) behavior in two EF tasks (n-back and switching task), and (3) we explored effects on spontaneous eye-blink rate (EBR) as a potential proxy for central dopamine activation. We successfully replicated condition effects on state extraversion and PA, but unexpectedly did not find effects on EF task performance. Exploratory analyses revealed associations of EF tasks with both trait extraversion and baseline PA, and a decreased EBR in the extraversion condition, while the introversion condition's EBR tended to increase. Albeit limited by the exploratory character of the latter analyses and the switching task's low reliability, these partly unexpected results may indicate that several cognitive and motivational processes interact during state enactments. We discuss alternative explanations and suggest necessary methodological improvements, which could help future studies employing the current experimental design to approach potential causal mechanisms behind personality-EF associations.

Keywords: extraversion, executive functions, stability-flexibility, positive affect, eye-blink rate

Executive Functions are Associated with Trait (but not State) Extraversion

Both trait extraversion and positive affective-motivational states have been linked to executive functions (EFs) in a growing number of studies (Fröber & Dreisbach, 2014, 2016; Wacker, 2018). While the causal effect of positive affective-motivational states on EFs is already quite established, the causal status underlying associations between trait extraversion and EFs remains unknown. It could be that certain features of extraversion influence EFs, that individual differences in EFs cause individuals to act in a more or less extraverted way (as proposed by Lieberman & Rosenthal, 2001) or that both trait extraversion and EFs are influenced by a third variable, such as shared neural, potentially dopaminergic mechanisms, without directly affecting each other (Herrmann & Wacker, 2021). As PA and components of reward processing are also central parts of trait extraversion (Smillie et al., 2019), a manipulation of extraverted states might have effects on EFs similar to those of positive affective-motivational states. Investigating causal effects of extraverted states on EFs, and potentially even on dopaminergic mechanisms, can contribute to a better understanding of the causal relationship between trait extraversion, EFs, and their underlying neural mechanisms. The present study therefore aimed to (1) replicate previous findings on affective consequences of an experimental behavioral manipulation of state extraversion, (2) investigate whether this manipulation of state extraversion has not only affective but also cognitive consequences, measured by performance in EF tasks, and (3) explore potential effects on the spontaneous eye-blink rate (EBR) as a potential marker of dopaminergic activation.

Extraversion, Executive Functions and Positive Affect

A growing number of studies suggests that extraverts and introverts differ in EFs such as working memory updating and shifting (or more generally, cognitive flexibility; Berse et al., 2014; Herrmann & Wacker, 2021; Wacker et al., 2006; Wacker, 2018). The two EFs updating and shifting are yet to reach a stage of consensus on their definitions, which are currently rather broad and partly overlapping in the sense that they both entail processes to adaptively update working memory content (Boot et al., 2017; Paul et al., 2021). The EF *updating* entails processes to continuously monitor, retrieve, transform, and substitute working memory content (Ecker et al., 2010; Miyake & Friedman, 2012). The EF *shifting* can be understood as a rather process-oriented term referring to the broader concept of the stability-flexibility balance (Herrmann & Wacker, 2021). Cognitive flexibility describes a state of rather easily *shifting* the attentional focus towards new goals or task-sets. It is balanced with its counterpart cognitive stability, which describes the active maintenance of current goals or task-sets (Cools & D'Esposito, 2011).

Associations between EF updating and trait extraversion have been reported for the n-back task, which measures updating by asking participants to continuously indicate whether a stimulus is identical to the stimulus presented n positions before. Especially the agentic aspect of extraversion including assertiveness, activity, and having a sense of accomplishing goals (Depue et al., 1994; Depue & Collins, 1999) has been found to be positively associated with performance in 2- and 3-back versions of the n-back task, indicating that higher agentic extraversion is associated with better performance (Gray & Braver, 2002; Herrmann & Wacker, 2021; Lieberman & Rosenthal, 2001; Wacker et al., 2006). There might even be a general pattern across updating tasks, as similar results have been reported for other updating tasks, again with a positive relationship between trait extraversion and updating performance (Campbell et al., 2011; Murdock et al., 2013).

The relationship between trait extraversion and EF shifting seems less clear. Previous studies found the relationship between trait extraversion and shifting to be positive (Berse et al., 2014; Herrmann & Wacker, 2021), negative (Wacker, 2018), non-existent or ambiguous (Murdock et al., 2013; Vaughan & Edwards, 2020). Interestingly, there is ample evidence for EF shifting, and the broader concept of stability-flexibility, being influenced by positive affective-motivational states, such as state PA, approach motivation, and reward (for reviews see Paul et al., 2021; Dreisbach & Fröber, 2019). Stability-flexibility seems to be constantly adapted in response to affective-motivational states to meet environmental demands (Dreisbach & Fröber, 2019). More specifically, a wider attentional scope and increased cognitive flexibility have been found for positive affective states in combination with a *low* approach motivation, which has been suggested to be an adaptive response to environments which allow for exploration (Paul et al., 2021). Conversely, a narrower attentional scope and higher cognitive stability have been found for positive affective states in combination with *high* approach motivation, suggesting they might be an adaptive response to situations of goal striving (Paul et al., 2021). Rewards have been theorized to affect the stability-flexibility balance in a similar manner: For performance-contingent rewards, which presumably reflect a positive affective state with high approach motivation, flexibility was found to decrease. Reversely, flexibility was found to increase for rewards which were not performance-contingent but randomly presented (Fröber & Dreisbach, 2014). As evidence for links between trait extraversion and stability-flexibility is mixed at best, it might be worthwhile to also consider the role of these states as they have not only been demonstrated to influence stability-flexibility, but also have a higher chance of being displayed by extraverted, compared to introverted, individuals (Costa & McCrae, 1980; Steel et al., 2008).

According to the psychobiological theory of extraversion, the strong link between extraversion and positive emotions reflects individual differences in approach motivation (Depue & Collins, 1999). The theory proposes that higher extraversion partly emerges due to tonically higher levels of DA postsynaptic receptor activation, leading to an increased ascription of motivational salience to all sorts of incentive stimuli, a lower threshold of behavioral activation in response to them, and as a result, higher reward sensitivity (Depue & Collins, 1999). The strong link between extraversion and PA can be understood as the affective consequence of individual differences in reward pursuit and attainment (Smillie et al., 2019), and is a stable finding among studies on personality – well-being associations (Steel et al., 2008). The association between extraversion and reward processing is apparent in correlations of extraversion with scales of reward sensitivity and reward reactivity (Corr & Cooper, 2016), and behaviorally, with increased reward sensitivity as measured in the probabilistic reward task (Blain et al., 2021; Pizzagalli et al., 2005) as well as acquisition of contexts that predict reward (Depue & Fu, 2013). There further is encouraging accumulated evidence that extraversion is associated with neural markers for reward processing, such as stronger EEG reward-prediction error signal (Cooper et al., 2014; Neo et al., 2021; Smillie et al., 2011; Smillie et al., 2019) and higher reward-related activation in the brain's reward system in fMRI (Cohen et al., 2005).

Interestingly, PA is not only associated with trait extraversion (between individuals), but also state extraversion (within individuals): Individuals report higher PA when they are in a more extraverted state, regardless of their level of trait extraversion, or whether their extraverted state was induced/measured in the lab or in everyday live (Fleeson et al., 2002; Heller et al., 2007; Jacques-Hamilton et al., 2018; Margolis & Lyubomirsky, 2020; Sun et al., 2017; Wilt et al., 2012; Wilt et al., 2017). When investigating associations between trait extraversion and EFs, it might therefore be a fruitful approach to also consider extraverts' higher likelihood of being in a state of high PA and high approach motivation. The current study follows this idea by investigating whether a direct manipulation of state extraversion has effects on EFs.

Traits are Density Distributions of States

The finding that state extraversion boosts PA mostly irrespective of trait extraversion supports the view of traits as density distributions of states (Fleeson & Jayawickreme, 2015, 2021). Over time and across situations, a person's *states* on the extraversion continuum form a density distribution representing that person's *trait* extraversion. In other words, a trait like extraversion is defined by the frequency of respective states across situations and should therefore not be viewed as an entity in itself. The density distribution of a person high on trait extraversion overlaps remarkably with the density distribution of a person low on trait extraversion (Fleeson & Gallagher, 2009). This means that both extraverts and introverts *can* enact most states on the extraversion continuum, with the only difference being the frequency in which these states actually are enacted, underlining the importance of considering, or even manipulating, states to better understand trait effects.

The view of traits as density distributions of states raises the question whether state extraversion is associated with PA and EFs in a similar way as trait extraversion is. Effects of state extraversion on PA are well-documented, but state extraversion has, to our knowledge, not yet been measured or manipulated to investigate effects on the EFs updating or shifting. Our aim was therefore to investigate whether a behavioral manipulation of state extraversion not only causes changes in PA, but also has an effect on EFs, potentially similar to the effects reported for trait extraversion. We applied the enacted extraversion paradigm (Fleeson et al., 2002; Sun et al., 2017), which has regularly been used as an experimental manipulation to investigate mostly the affective consequences of extraverted behavior as well as explanatory mechanisms behind it (e.g. Davydenko et al., 2020; Smillie et al., 2015; Sun et al., 2017; Zelenski et al., 2012). In this paradigm, a group of usually three participants engages in a discussion task after being individually instructed to act either extraverted or introverted (compared to no further instructions in the control condition). Effects of enacted extraversion/introversion on PA have been demonstrated in all of the mentioned studies, with participants of the extraversion condition showing an increase, and participants of the introversion condition showing a decrease in PA. Interestingly, Zelenski et al. (2012) further found that counterdispositional behavior, i.e. when the enacted behavior differs from dispositional behavior, can further have cognitive effects: Dispositional extraverts who were instructed to act introverted produced poorer Stroop performance than dispositional extraverts in the other two conditions and all dispositional introverts. However, Stroop performance is ascribed to EF inhibition (Gratton et al., 2018), not to EF updating or shifting. To our knowledge there are currently no further studies on cognitive effects of the enacted extraversion paradigm, and potential neural mechanisms behind them remain entirely unknown.

Dopaminergic Mechanisms Behind Executive Functions and Extraversion

The dopaminergic mechanisms behind EFs have long been demonstrated for updating (Luciana et al., 1992) as well as shifting (Owen et al., 1993) through various approaches, such as lesion and neuroimaging studies (for a meta-analysis, see Niendam et al., 2012), pharmacological approaches (Seamans & Yang, 2004) and computational modeling (e.g. Chatham et al., 2011). This work identified a large, integrated network of frontal, cingulate, parietal, and subcortical regions which support EFs (Niendam et al., 2012). Among these regions, DA in prefrontal and striatal areas plays an essential role for stability-flexibility, with striatal DA regulating the updating/maintenance of working memory representations in prefrontal areas via a situationally adaptive updating threshold (for a review see Cools, 2019).

Not only EFs but also extraversion has been associated with central DA function in striatal areas, which sparked the idea that the relationship between extraversion and EFs might be attributable to shared dopaminergic processes (Herrmann & Wacker, 2021). So far, there is evidence for extraversion-related structural differences in the brain mostly for DA-rich striatal regions. For instance, previous research reported individual differences in striatal DA receptor density (Baik et al., 2012), in gray matter volume in the caudate and nucleus accumbens (Lai et al., 2019; Li et al., 2019), cerebral perfusion in the caudate and putamen (O'Gorman et al., 2006) and resting state glucose metabolism in the right putamen (Kim et al., 2008).

In addition, pharmacological studies demonstrate extraversion-related individual differences in the effects of DA D2 drugs. The DA D2 antagonist sulpiride, which mostly acts on the striatum (Mehta et al., 2001; Mehta et al., 2004), has for example been demonstrated to elicit changes in interaction with extraversion in several measures, such as EEG theta activity (Chavanon et al., 2013), EEG alpha activity (Chavanon et al., 2007; Wacker, 2018), EEG feedback-related negativity (Mueller et al., 2014), and performance in EF tasks (Herrmann & Wacker, 2021; Wacker et al., 2006). Furthermore, varying doses of the DA D2 agonist bromocriptine have been demonstrated, again in interaction with extraversion, to elicit changes in fronto-striatal connectivity and working memory tasks (Wallace et al., 2011), as well as cardiovascular effects (Wacker & Stemmler, 2006).

Extraversion has further been occasionally connected to individual differences in the spontaneous eye-blink rate (EBR; Jongkees & Colzato, 2016; Unsworth et al., 2019), which has been discussed as an easily-accessible, non-invasive proxy for striatal DA function (Jongkees & Colzato, 2016). Despite some doubts on the relationship between the EBR and striatal DA due to null findings in PET studies on DA receptor availability or synthesis capacity (Dang et al., 2017; Sescousse et al., 2018), there is a substantial amount of studies measuring alterations of the EBR in the context of reward, EFs, and attention (for a review see Jongkees & Colzato, 2016). The EBR has also already been applied in the context of shifting and working memory tasks, demonstrating a positive association with flexibility (at the cost of increased distractibility) and a negative association with accuracy in the 3-back task (Dreisbach et al., 2005; Pajkossy et al., 2018; Unsworth et al., 2019; Zhang et al., 2015). For experimental paradigms in need of an easily-accessible, albeit more indirect, proxy for striatal DA function, we therefore consider the EBR as promising to offer first insight into neural dopaminergic mechanisms behind the relationship between extraversion and EFs.

Research Question and Hypotheses

So far it remains unclear whether individual differences in central DA activation only lead to individual differences in state extraversion, and indirectly trait extraversion, or whether extraverted behavior also leads to individual differences in central DA activation. From a conceptual point of view, experimental approaches from different directions are a necessary step towards causal inference. In contrast to pharmacological studies, which manipulate DA activation and investigate the effects on EF tasks, affect, and/or neural markers in interaction with trait extraversion, our current approach therefore takes a slightly different route: We aim to manipulate state extraversion to directly investigate and explore its effects on affective, cognitive and neural measures.

In the present study we investigated the effects of extraverted versus introverted states induced via instructions to act more extraverted versus introverted in a group discussion on performance in an updating and a shifting task. As a starting point for the investigation of neural correlates, we exploratively measured spontaneous EBR before and after the states were induced. Our research question was whether acting extraverted (vs. introverted vs. control) (1) has effects on state PA, replicating previous findings, (2) has effects on EFs measured with two tasks, (3) has effects on striatal DA activation as measured with the EBR. We expected acting condition (enacted extraversion versus introversion versus control) to have an effect on state extraversion and state PA similar to previous studies using the enacted extraversion paradigm, and on EFs measures similar to effects suggested by previously reported trait extraversion-EF associations. Regarding the EBR, we expected acting condition to have an effect on the change in EBR from baseline, but did not hypothesize the direction of this effect. Although there may be evidence for an association between EBR and higher striatal DA activation (Jongkees & Colzato, 2016), it is unclear whether our measurement *after* the state enactment captures the same processes as *during* the state enactment.

Methods

Participants

We analyzed data from 108 participants who were tested in groups of three same-sex participants and all met the inclusion criteria of right-handedness, self-rated physical and mental health, German language skills (native or nearly native speaker), age between 18 and 35 years (*M* = 24.9; *SD* = 4.1), and sexual orientation (heterosexual). Heterosexual orientation was chosen as an inclusion criterion to minimize potential effects of sexual attraction between participants within same-sex groups. Participants received a monetary compensation of 30 € (or course credit) for their three hours of participation. This study was approved by the University's local ethics committee. We excluded the data from two incomplete groups before accessing any of the data because the different interpersonal dynamic between two instead of three participants might influence the effects of the experimental manipulation. Our sample size was determined by the goal to have a power of 95% to find a small effect size of $f = 0.1$ ($\alpha = .05$) in a MANOVA with three groups (enacted extraversion vs. enacted introversion vs. control) and three response variables using G*Power 3 (Faul et al., 2007).

Design

We used a randomized controlled experimental protocol similar to previous investigations with the enacted extraversion paradigm (Fleeson et al., 2002; Smillie et al., 2015, Study 2; Sun et al., 2017, Study 2). Participants were assigned to one of three acting conditions (enacted extraversion vs. enacted introversion vs. control), engaged in two group discussion tasks, and rated their own and their discussion partners` behavior after each discussion.

Material and Measures

Behavioral Instructions

As part of their written instructions for the group discussion tasks, participants received individual behavior instructions to secretly play a special role in the group discussion. Participants were not informed that their group members might also have special behavior instructions.

Depending on acting condition, they were instructed to act *bold, talkative, energetic, assertive,* and *adventurous* (extraversion condition), or *reserved, quiet, lethargic, passive, compliant*, and *unadventurous* (introversion condition; cf. Fleeson et al., 2002; Smillie et al., 2015; Zelenski et al., 2012). Participants in the control condition received no further behavioral instructions but a lengthier, informationally equivalent general task description.

Group Discussion Tasks

We presented the “Lost at Sea” and “Survival in the desert” tasks (cf. Fleeson et al., 2002) in counterbalanced order. The experimenter presented each survival scenario to the participants by reading a standardized instruction, and asked them to collaboratively discuss and rank the usefulness of 15 objects, represented on labelled photo cards on the table.

State Extraversion

We used a list of adjectives (Goldberg’s adjective Mini-Markers, 1992) as a measure of state extraversion to assess whether participants enacted their respective instructions. The list contains 10 adjectives measuring extraverted behavior (shy [r], compliant [r], reserved [r], lethargic [r], bold, talkative, energetic, active, assertive, adventurous) and eight filler items (e.g. creative, systematic) which are answered on a 7-point Likert scale (1 = not at all, 7 = very well). Participants were first asked to rate themselves, and afterwards to rate their group members. We used the mean value of the 10 adjectives as a measure of self- or informant-rated state extraversion. The total state extraversion was computed as the mean value of the one self-rating and the two informant-ratings.

State Positive Affect

We assessed state PA with four items referring to PA (e.g. happy, cheerful, proud, active) embedded in eleven nine-point intensity ratings of several emotional states (e.g. fearful, sad, angry), including eight scales with a unipolar (0 = not at all applicable, 8 = very applicable) and three with a bipolar format (4-0-4). Depending on the targeted rater perspective, we asked for self-ratings and ratings of the perceived state PA of the other participants. The total state PA was computed as the mean value of one self-rating and two informant-ratings.

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3-back Task

We presented the same task as in Herrmann and Wacker (2021) with 57 practice trials and then 117 trials, each consisting of one white letter on a black screen (500 ms) followed by a pause (1650 ms), in a fixed random order, in which participants had to indicate whether the currently presented letter was identical to the letter 3 trials before (40 target trials) or not (77 non-target trials; including 12 trials as 1- and 2-back to prevent answering based on familiarity). Participants responded via mouse-click (left for “yes”, right for “no”), with standardized verbal feedbacks (350 ms) after each trial (“correct”, “incorrect”, “slow”) being included reinforce fast and accurate performance. An individual latency criterion was used to provide “slow” feedback (90th percentile of a participant’s reaction time distribution in the last 50 practice trials) to reduce variation in potential speed-accuracy-tradeoffs (cf. Wacker et al., 2006). The 3-back task took participants on average 14 min (*SD* = 2.5). Performance was measured with a focus on target trials, for which we computed mean accuracy (correct vs. incorrect) and mean reaction times (RTs) of correct responses, to allow comparison with previous findings.

Switching Task

We first presented 20 practice trials in which participants identified separately displayed letters as vowel/consonant or numbers as odd/even, followed by six 60-trial blocks with pairs of colored letters or numbers (A/E/O/U/K/M/R/S; and 2/3/4/5/6/7/8/9) in alternating order, for which participants identified the stimulus in the target-color as vowel/consonant or odd/even and (right/left mouse-click, respectively), and ignored the stimulus in the distractor-color (as in Herrmann & Wacker, 2021). The respective target- and distractor-colors were presented at the beginning of each block (e.g. “target color is red”) and at the “switch” of colors after 40 trials (e.g. “switch to green”). The switch happened in two different qualities: In the “learned irrelevance” condition, the previously *irrelevant* distractor-color became the new target color, while a new color became the distractor-color. In the “perseverance” condition, the previous target-color now became the distractor color, inducing a tendency to *persevere* with their focus on the former target-color, while a new color became the present target-color. For learned irrelevance blocks, a better shielding from new, distracting information (new distractor color) is advantageous, which should lead to lower switch costs with higher stability and higher costs with higher flexibility. In perseverance blocks, higher flexibility should be advantageous because it allows (1) faster disengagement when the pre-switch target color becomes the post-switch distractor color, and (2) easier updating of a new color as target-color, whereas higher stability should impede both disengagement and updating.

The switching task took participants on average 21 min (*SD* = 3.2). For better comparison with previous findings we analyzed the switch costs (RT increase from the five correct trials pre versus post switch) from the learned irrelevance minus perseverance condition ("switch cost difference"). A higher positive switch cost difference, caused by relatively higher switch costs in the learned irrelevance compared to the perseverance condition, is theoretically associated with higher flexibility. Conversely, a lower or even negative switch cost difference is in turn theoretically associated with higher stability.

EOG

We measured an EOG for 5 min under resting conditions in one baseline measurement (T0) and one measurement after each group discussion (T1, T2). We applied three self-adhesive, disposable electrodes (Hasomed) on the disinfected facial skin with one electrode above and below the center of the left eye, and one grounding electrode on the forehead, and connected them with a BioPac MP36 system via cables. Signals were recorded on the computer with the software Biopac StudentLab (Version 4.1 for Windows 7), using the built-in standard bipolar electrode configuration for EOG signals to measure the voltage difference between the two electrodes with respect to the grounding electrode.

We informed participants that the electrodes would measure facial muscle activation to prevent participants from having an increased awareness for their own eye-blinks. Participants were seated in front of their computer screen during the measurement, were asked to look at a black cross in the center of the white screen, facing away from their group members. As participants were required to change their seats for the group discussions, we attached the cables to the facial electrodes only for the time of EOG measurements. External factors which could potentially affect the EBR, such as lightning or draft of air, were held as constant as possible by constant artificial lightning and shutting down air circulation 15 min prior to each EOG measurement.

We preprocessed the EOG data blindly to acting condition using Brain Vision Analyzer 2.0 (Brain Products GmbH, Gilching, Germany). We sampled the EOG signals at 500 Hz with cutoff filters of 0.5 Hz and 40 Hz. We counted the number of eye-blinks in 10-second segments in a two-step process. In a first step we used the built-in Gratton & Coles algorithm (Gratton et al., 1983) to detect candidate eye-blinks automatically. In a second step we marked all segments containing noise signals which could mask eye-blink signals for removal, visually inspected candidate eye-blinks detected by the algorithm, and corrected wrongly detected or missed eye-blinks if necessary. In total we removed 51 segments from the whole dataset, which is less than 1% of the total number of segments in the dataset. The mean number of valid segments per measurement was close to the initial number of 30 segments(M_{T0} = 29.9, M_{T1} = 29.6, M_{T2} = 29.8), indicating a high quality of the three EOG recordings. All participants had at least 4 min (24 segments) of noise-free data in each measurement. The individual EBR per minute was calculated by multiplying the individual mean EBR per segment by six, resulting in three mean (one baseline, two post-discussion) EBRs per participant.

Procedure

We applied a procedure similar to previous studies using the enacted extraversion paradigm (e.g. Smillie et al., 2015; Sun et al., 2017). An overview of the laboratory setup can be viewed in Figure 1. Participants were tested in groups of three. After providing informed consent, participants were block-randomized per group to three acting conditions (acting extraverted, acting introverted, control) and seated at separate computers for baseline measurements (T0) where they completed electronic questionnaires assessing personality, state PA and general well-being. The experimenter then installed self-adhesive electrodes for the EOG. After a five-minute resting EOG, the electrode cables were removed, while the electrodes remained attached to participants’ faces for later resting

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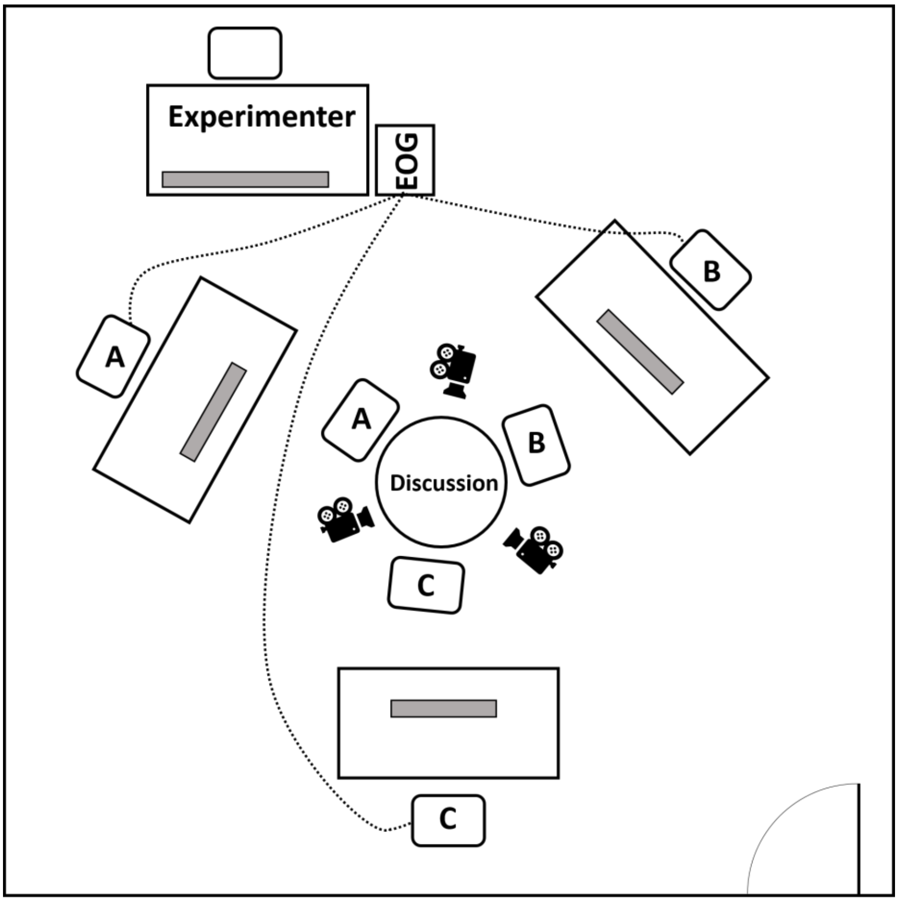
Figure 1

Laboratory Setup



Note. Rounded rectangles represent seats. Participants A, B, and C alternated between seats in front of screens (for all measurements), and around the table in the center (for the group discussions).

EOG measurements. After cable removal, participants received written instructions about the first out of two group discussion tasks, as well as enactment instructions for their respective acting condition (order of discussion tasks randomized across groups). They were then seated at a round table and presented a pile of cards with task items to foster engagement with the material. Participants were given ten minutes to discuss the order of the cards while being recorded by three cameras for potential later analyses of behavior and expressed emotion not relevant to the current research question. Since participants in a pilot study occasionally finished the task after a few minutes, which could result in less accurate behavioral ratings, participants in this study were explicitly asked to engage in the task throughout the ten minutes and to not finish earlier. Afterwards participants returned to their individual computers for measurements of T1, had their EOG electrodes connected to the electrode cables and had another five-minute resting EOG. Then, the electrode cables were again removed and, on average 12 min after the first discussion ended (*SD* = 1.8), participants completed one out of two EF tasks (3-back task or switching task) with the order of the tasks randomized. After the task, participants completed self- and informant ratings of state PA, but no ratings of extraverted behavior to not raise awareness for potential acting instructions of the respective other participants. Next, participants read the instructions for the second group discussion task, were reminded of their enactment instructions, came together at the round table in the middle and again participated in a ten-minute group discussion while being recorded. For measurements of T2, the discussion was again followed by a five-minute resting EOG, and, on average 11 min after the second discussion ended (*SD* = 1.5), the second out of two EF tasks. Finally, participants completed self- and informant ratings of state PA, state extraversion, further well-being measures not relevant to the current research question, provided demographic information, and were debriefed, thanked, and reimbursed for their participation.

Data Analysis

State ratings after the two discussion tasks (T1 and T2) were averaged across the two time points (“T1T2”) to increase reliability. To reduce the potential influence of rater perspectives, we focused our analyses on composite scores of self- and the two informant-ratings per participant. Task performance measures were square-root- (3-back RTs), boxcox- (3-back accuracy), or log10- (switching measures per condition) transformed to normalize distributions. We registered performance-based exclusion criteria for both EF tasks before data analysis, excluding (1) trials with RTs below 200 ms or above 2000 ms, (2) 3-back data of participants who detected less than 50% of all non-target trials or less than 10% of all target trials, (3) switching blocks of participants who had an error rate of more than 50% in the 40 pre-switch trials, or at least three errors in the six trials before and/or after the switch, (4) switching data of participants with less than two valid blocks per condition.

As participant data are nested within testing groups, all manipulation checks and main models were conducted as multilevel models including a random intercept for group whenever the model converged. We fitted the models using a restricted maximum-likelihood estimation and obtained p-values with the Satterthwaite's approximation. If the model did not converge, we removed the random intercept to analyze the same fixed effects with linear regression models. As manipulation checks we investigated whether acting condition significantly explained state extraversion and state PA, and whether the effects interacted with trait extraversion in consecutive linear models. For our main analysis, we analyzed the effect of acting condition on multivariate task performance in a multivariate multilevel model, for which we z-transformed the three dependent variables and treated them as three measurements within a person by including a random intercept for participants (and for groups). We followed up with one model per outcome variable (switch cost difference, 3-back RTs, 3-back accuracy) and again acting condition as predictor. We further investigated pairwise correlations among trait, state and task variables within and between conditions. In an additional exploratory analysis, we investigated whether the acting condition caused a change in EBR as a marker for central DA activation in a linear model.

Results

Data Cleaning and Reliability

Table 1 displays descriptive statistics of age, personality, and state measures per substance condition and in total. Acting conditions did not differ significantly in age, NEO traits, or baseline PA (all *p*s > .20). Based on the registered exclusion criteria for the switching and 3-back task, we excluded five participants each (one participant was excluded from both tasks). We additionally excluded switching data of one participant (missing data due to program error during task completion), and 3-back data of one participant with a high number of misses (37%) but otherwise low to ordinary performance (cf. Herrmann & Wacker, 2021).

Spearman-Brown corrected split-half reliability between the two 3-back blocks was excellent for mean target RTs (*Rel*. = .912), and good for accuracy (*Rel*. = .803). Reliability among blocks was unsatisfactory for switch costs (learned irrelevance: Cronbach´s $\alpha = .407$; switch costs perseverance: Cronbach´s $\alpha = .203$) and the switch cost difference (Cronbach´s $\alpha = .282$). As discussed before (Herrmann & Wacker, 2021), low reliability might be design-inherent as the switching task was constructed to investigate within- (rather than between-) participant effects. This limits conclusions from our analyses on this task, which we will take up in more detail in the discussion. Behavioral ratings of state extraversion had excellent internal consistency for self- and informant-ratings (self: Cronbach´s $\alpha = .945$, informant: Cronbach´s $\alpha = .934$). Self-ratings and the averaged two informant-ratings of state extraversion correlated highly significantly ($r(106) = .85$, $p < .001$). For state PA, test-retest reliability comparing ratings after first and second discussion was good for total ratings (*Rel*. = .829), self-ratings (*Rel.* = .815) and the averaged two informant ratings (Rel. = .778). State PA ratings after both discussions also displayed good internal consistency for self-ratings (Cronbach's alpha T_1 = .791, Cronbach's alpha T_2 = .865) and for each informant rating separately (Cronbach's alpha T_1= .803, Cronbach's alpha T_2= .838). Self-ratings and the averaged two informant-ratings of state PA correlated significantly (T1: $r(106) = .34$, $p < .001$; T2: $r(34) = .28$, p =.003).

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Table 1

Means, Standard Deviations (per Acting Condition and in Total), and ANOVA Results of All Measures

Variable	Enacted Extraversion		Control		Enacted Introversion				Total	
	M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*F*	*p*	*M*	*(SD)*
Age	24.6	(4.07)	25.6	(4.49)	24.5	(3.61)	0.89	.42	24.9	(4.07)
NEO scales										
Neuroticism	2.7	(0.58)	2.8	(0.48)	2.8	(0.54)	0.61	.54	2.8	(0.53)
Extraversion	3.3	(0.38)	3.4	(0.33)	3.3	(0.45)	0.52	.59	3.3	(0.39)
Agentic	3.0	(0.47)	3.1	(0.45)	3.0	(0.44)	0.29	.75	3.0	(0.45)
Affiliative	3.5	(0.57)	3.5	(0.40)	3.4	(0.66)	0.21	.81	3.5	(0.55)
Openness	3.6	(0.40)	3.6	(0.31)	3.6	(0.42)	0.17	.84	3.6	(0.38)
Agreeableness	3.5	(0.39)	3.4	(0.35)	3.4	(0.39)	0.57	.57	3.4	(0.37)
Conscientiousness	3.5	(0.50)	3.5	(0.39)	3.4	(0.41)	0.39	.68	3.5	(0.43)
State measures										
Positive affect (baseline)	5.2	(1.38)	5.1	(1.39)	4.5	(1.94)	2.32	.10	4.9	(1.61)
Positive affect (T1T2)	5.3	(0.84)	5.0	(0.83)	3.6	(0.79)	47.00	**<.001**	4.7	(1.12)
Extraverted behavior (T2)	5.1	(0.42)	4.6	(0.57)	2.4	(0.73)	205.4	**<.001**	4.1	(1.29)

Note. N = 108 with equal numbers per condition. Significant effects in bold. T1T2 = mean value from state ratings after both discussions. T2 = state ratings after second discussion.

State Effects

Table 1 displays mean ratings of state extraversion and state PA per condition and in total, and condition comparisons with ANOVA. All analyses not based on average ratings (i.e., T1 and T2, or self- versus informant-ratings separately) are reported in the Supplement. As expected, the extraversion condition displayed highest values in both state measures, and the introversion condition displayed the lowest. We additionally analyzed contrasts between acting conditions with multivariate multilevel models as participant data are nested within groups. More specifically, we used acting condition and its interaction with trait extraversion to explain mean ratings of state extraversion or state PA, and included a random intercept for group.

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For state extraversion, we found a strong negative effect for the contrast control – introversion (*B* = -2.195, 95% CI [-2.474, -1.917], *p* < .001), and a positive effect for the contrast control – extraversion (*B* = 0.435, 95% CI [0.156, 0.713], *p* = .003). Trait extraversion did not reveal a main effect (*p* = .195), but its interaction with the contrast control – introversion showed a significant negative effect (*B* = -0.847, 95% CI [-1.598, -0.096], *p* = .027), indicating that individuals high in trait extraversion showed particularly reduced state extraversion in the introversion condition versus control. The model explained more than two thirds of the total variance in state extraversion ratings (R^2 = .797).

For state PA, we again found lower values in the introversion condition compared to control (*B* = -1.426, 95% CI [-1.708, -1.144], *p* < .001), and higher values in the extraversion condition compared to control (*B* = 0.322, 95% CI [0.040, 0.604], *p* = .026). The main effect of trait extraversion was nonsignificant (*p* = .258), while the interaction between trait extraversion and the contrast control – introversion was (*B* = -0.940, 95% CI [-1.802, 0.077], *p* = .033), with the pattern mirroring the one observed for state extraversion (i.e., larger differences between control and introversion for individuals high in trait extraversion). Acting condition explained more than two thirds of the total variance in state PA considering the random intercept for group (conditional R^2 = .730), and nearly half of the total variance if not considered (R^2 = .464). As shown in Table 1 and Figure 2, state PA unexpectedly tended to differ at baseline, which might confound the effect of the acting conditions. We therefore created a change score of state PA (T1T2 minus T0), which was significantly lower for the introversion versus extraversion condition (*B* = -0.984, 95% CI [-1.814, -0.155], *p* = .020), tended to be lower for introversion versus control (*B* = -0.799, 95% CI [-1.629, 0.030], *p* = .059), but did not differ between extraversion and control (*p* = .657). We further analyzed the correlation between state extraversion and state PA. For all three conditions together, the correlation between the two state measures was highly significant (*r*(106) = 0.797, *p* < .001). The correlations were of similar size for the extraversion (*r*(34) = .56, *p* < .001), introversion (*r*(34) = .56, *p* < .001), and control condition (*r*(34) = .59, *p* < .001).

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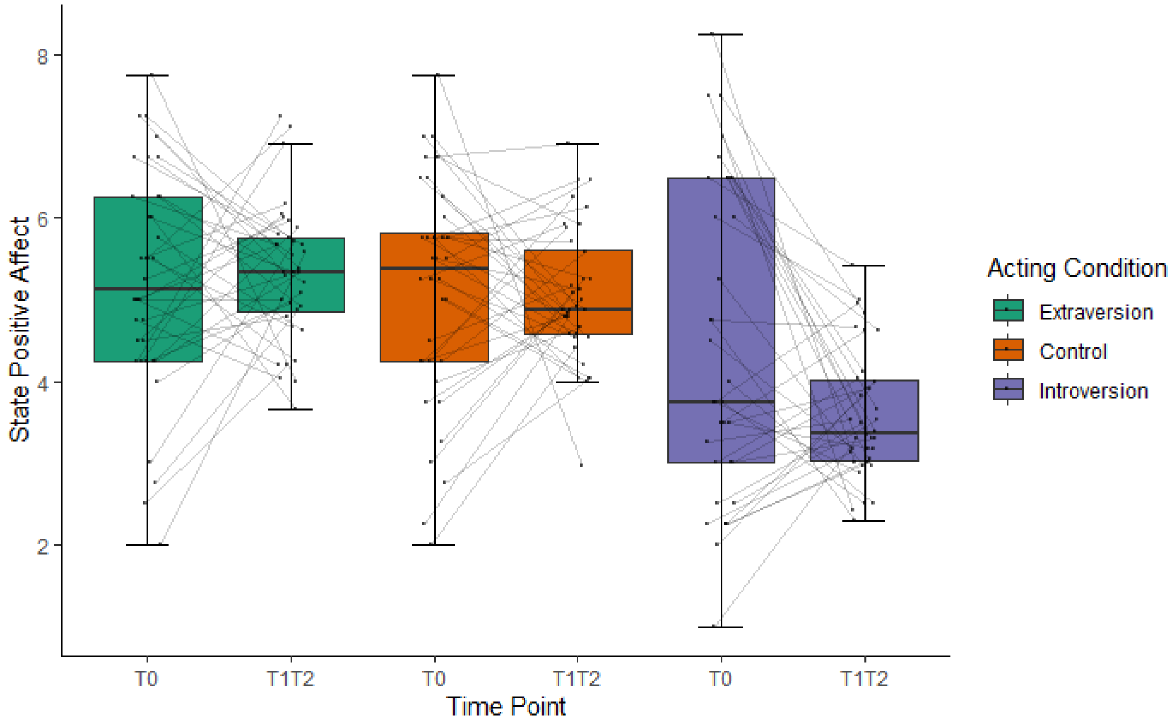
Figure 2

Boxplots of State Positive Affect as a Function of Acting Condition and Time Point



Note. T0 = Baseline measurement; T1T2 = mean of the measurements at T1 and T2 (after group discussions). Change in individual scores from T0 to T1T2 is presented as individual dots connected with lines.

Main Analysis

Results of the main multivariate multilevel model are displayed in Table 2. In brief, we found no significant effects of acting condition on any EF task performance measure. We explored whether a potential effect was masked by computing a difference score between the two switching conditions, but an alternative model with the two switch cost measures (learned irrelevance and perseverance condition) instead of the switching cost difference still did not reveal any significant effects.

When analyzing the three EF task performance measures separately as a next analysis step, acting condition also had no significant effect on 3-back RTs (all *ps* > .155), 3-back accuracy (all *ps* > .714) or the switch cost difference (all *ps* > .185). As effects might only be visible when considering shared variance among the tasks, we included measures of the respective other task as covariates into each model, but still did not find any effects. The switch cost difference or any interaction with acting condition did not reveal significant effects on 3-back RTs (all *p*s > .308), 3-back accuracy (all *p*s > .489), or vice versa (all *p*s > .633). We further investigated whether potential effects might be masked by EF task order or differences in delay between the end of discussion and EF task onset. However, acting condition neither affected 3-back task performance for participants who did the 3-back task first (*p*s > .216), nor switching task performance for participants who did the switching task first (*p*s > .194). Adding task order as a covariate into the multivariate multilevel model, or into multilevel models for each task measure, did not reveal any significant effects (all *p*s > .117; see Supplement). The duration between the end of discussion and EF task onset did not predict task performance (*p*s > .430).

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Correlations

Pairwise correlations across acting conditions are displayed in Table 3. As we consider the correlational analysis as mostly descriptive, we did not correct for multiple comparisons. We found the expected positive correlation between 3-back RTs and 3-back accuracy across acting conditions (*r*(100) = .470, 95% CI [.302 – .608] , *p* < .001), indicating a speed-accuracy tradeoff. There was also an unexpected association between trait extraversion and longer target RTs (*r*(97) = .240, 95% CI [.045 – .418] , *p* = .017), and a slightly less pronounced association between target RTs and the agentic aspect of trait extraversion (*r*(99) = .200, 95% CI [.008 – .383] , *p* = .042), while there was no association for target accuracy. The positive association between trait extraversion and the switch cost difference was only significant for agentic extraversion but not extraversion (agentic

Table 2

Multivariate Multilevel Model for Task Performance.

Effect	*B*	*SE*	*95% CI*		*p*
			LL	UL	
Intercept [3-back RTs; Control Condition]	0.182	0.175	-0.162	0.525	.298
Measure [3-back accuracy]	-0.224	0.230	-0.676	0.228	.331
Measure [Δ switch]	-0.037	0.233	-0.495	0.421	.874
Condition [E]	-0.18	0.242	-0.656	0.296	.456
Condition [I]	-0.361	0.247	-0.847	0.125	.145
Measure [3-back accuracy] * Condition [E]	0.241	0.318	-0.384	0.867	.448
Measure [Δ switch]* Condition [E]	-0.153	0.321	-0.786	0.479	.633
Measure [3-back accuracy]* Condition [I]	0.428	0.325	-0.211	1.067	.189
Measure [Δ switch] * Condition [I]	0.278	0.325	-0.362	0.918	.394

Note. N = 107. *CI* = confidence interval; LL = lower limit; UL = upper limit; Δ switch = switch costs of LI minus PE; aE = agentic extraversion. Significant effects in bold. Reference categories are 3-back RTs and the control condition.

extraversion: *r*(99) = .240, 95% CI [.048 – .417] , *p* = .015; extraversion: *r*(97) = .093, 95% CI [-.107 – .285] , *p* = .362), indicating higher flexibility with higher agentic extraversion.

Regarding state effects, state PA at baseline correlated positively with both agentic extraversion and extraversion in total (agentic extraversion: *r*(105) = .190, 95% CI [.000 – .368] , *p* = .015; extraversion: *r*(103) = .330, 95% CI [.150 – .494] , *p* = .001), but not at T1T2 (*p*s > .332). Neither state PA (T0 and T1T2) nor state extraversion were significantly associated with 3-back task performance or switch cost difference, except for a tendency of higher state PA at T1T2 to be associated with costs in the switching task's learned irrelevance condition (*r*(103) = -.190, 95% CI [-.370 – .000] , *p* = .050), and the switch cost difference (*r*(100) = -.180, 95% CI [-.359 – .019] , *p* = .076; all other *p*s > .313). Unexpectedly, state PA ratings (baseline and T1T2) further showed differential associations with the switch cost difference in different acting conditions, which will be more closely examined in an exploratory analysis below. As state extraversion was not associated with task performance, we did not perform our registered analysis on the potentially mediating role of state PA on this relationship. Correlations with the EBR will be addressed in the exploratory analysis.

Table 3

Pairwise correlations between the main variables across acting conditions

Variable	M	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. 3-back target RTs	665.8	160.9												
2. 3-back target accuracy	54.37	18.21	**.47*****											
3. LI switch costs	67.35	99.6	-.04	-.04										
4. PE switch costs	60.99	85.37	-.04	.07	-.03									
5. Switch cost difference	4.461	133.1	.01	-.10	**.74*****	**-.66*****								
6. NEO aE	3.026	0.452	**.20***	.08	.16	**-.19***	**.24***							
7. NEO E	3.327	0.385	**.24***	.04	.06	-.03	.09	**.62*****						
8. State E T1T2	4.046	1.292	-.08	.03	.04	.07	.01	-.06	-.10					
9. State PA T0	4.92	1.609	-.02	.03	-.02	.17	-.14	**.19***	**.33*****	.01				
10. State PA T1T2	4.65	1.118	-.04	-.02	-.19	.10	-.18	-.09	-.02	**.56*****	.04			
11. EBR T0	18.87	11.19	.02	.03	.03	-.09	.06	-.08	**-.19***	-.16	-.02	**-.24***		
12. EBR T1T2	18.22	12.32	-.01	.07	-.03	-.06	-.03	.03	-.17	-.18	-.07	-.14	**.85*****	
13. EBR change	-0.65	6.844	-.06	.08	-.11	.06	-.16	.19	.05	-.02	-.10	.18	**-.30****	**.25****

Note. N = 108. All measures are centered within condition. Significant correlations in bold. 3-back: 1.-2.: target RTs = mean RTs in correct target trials, target accuracy = mean accuracy in target trials. Switching (3.-5.): LI = Learned irrelevance condition, PE = perseverance condition, switch costs = mean RTs after minus before the switch, switch cost difference = switch costs of LI minus PE. NEO aE = NEO agentic extraversion, NEO E = NEO extraversion, EBR = eyeblink rate per minute, T0 = baseline, T1T2 = mean value of ratings after discussions at T1 and T2. EBR change = mean EBR of T1 and T2 minus mean EBR of T0.

*p < .05; **p < .01; ***p < .001

Appendix C

Exploratory Analysis

For a better overview on findings of the correlational analyses, we added trait extraversion or state PA ratings (at baseline and T1T2) as covariates into the main analysis univariate models to account for interaction effects between the respective covariate and acting condition, as well as for the dependent data structure. The effects of trait extraversion as a predictor for the switch cost difference and 3-back RTs just missed the significance threshold (p = .097 and p = .083, respectively), while effects of state PA on the switch cost difference were significant at baseline, but not T1T2: Baseline state PA tended to show a positive association with the switch cost difference in the control condition (B = 0.226, 95% CI [-0.007 – 0.459], p = .057), and a significantly more negative association in both extraversion and introversion conditions relative to control (extraversion: B = -0.393, 95% CI [-0.721 – -0.064], p = .020; introversion: B = -0.414, 95% CI [-0.702 – -0.126], p = .005).

To explore whether acting condition (and/or trait and baseline measures) affected brain DA, we assessed the EBR in a resting period at baseline and after both discussions (T1, T2). Table 3 displays pairwise correlations across acting condition between EBR measures and other main task measures, Table 4 displays descriptive statistics for the three time points of EBR measurements and

Table 4

Descriptive statistics of the eyeblink rate measurements

Measure	Enacted extraversion		Control		Enacted introversion		Total		Cronbach's alpha
	M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	*M*	*(SD)*	
T0	18.09	10.86	21.50	12.05	17.04	10.43	18.88	11.20	.95
T1	15.17	10.07	19.35	14.64	18.14	12.06	17.55	12.40	.97
T2	16.89	10.49	20.21	13.65	19.58	14.58	18.89	12.98	.96
EBR change	-2.06	6.13	-1.72	7.20	1.82	6.65	-0.65	6.84	.85
t(35)	2.02		1.44		-1.64		0.99		
p	.051		.160		.109		.322		

Note. N = 108. EBR change is computed as the mean EBR of T1 and T2 minus the mean EBR of T0. T-tests compare the EBR of T0 with the mean of T1 and T2.

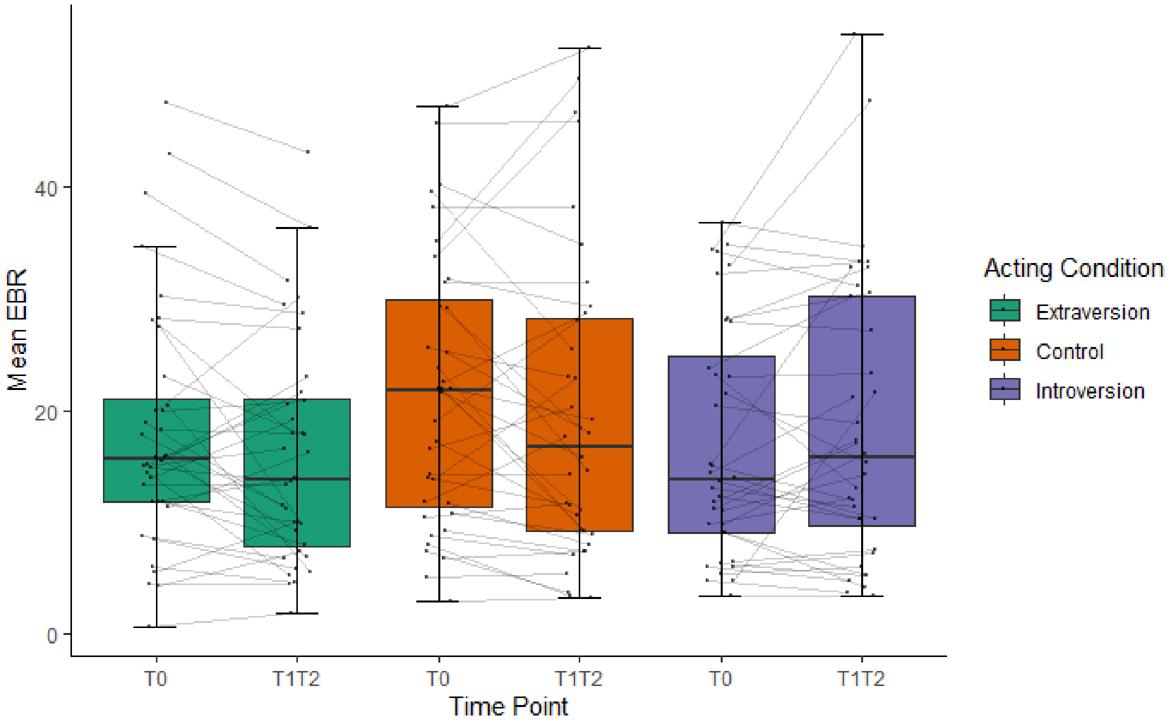
their change score per condition and in total. EBR showed high internal consistency of 1-min segments within each measurement (also see Table 4), and a high test-retest correlation between T1 and T2 (*r*(106) = .890, 95% CI [.839 – .922], *p* < .001). Baseline EBR did not differ between acting conditions (accounting for groups; *F* (2, 70) = 1.553, *p* = .229). Across conditions, EBR tended to decrease between the baseline and T1 (*t*(107) = 1.88, *p* = .063), and significantly increased from T1 to T2 (*t*(107) = -2.30, *p* = .023). For the following analyses we computed the mean EBR for T1 and T2.

In a multilevel model including a random intercept for group, we found extraversion-related individual differences in baseline EBR: Trait extraversion was negatively associated with baseline EBR (*B* = -0.515, 95% CI [-1.013 – -0.017], *p* = .043), while its agentic subscale was not (*B* = - 0.189, 95% CI [-0.621 – 0.242], *p* = .387). The significant negative correlation between baseline EBR and trait extraversion, but not agentic extraversion (see Table 3) matched this pattern. The baseline EBR was negatively correlated with state PA at T1T2 (*r*(106) = -.240, 95% CI [.409 – .052], *p* = .013), but this association disappeared when included into a multilevel model to account for the dependent data structure (*p* = .267).

We further explored whether acting condition explained a change in EBR from baseline to T1T2. As displayed in Table 4, the extraversion condition's decrease in EBR just missed the significance threshold (*p* = .051), while the introversion condition's EBR descriptively increased. The EBR change for the extraversion versus introversion condition differed significantly (*t*(69.54) = -2.576, *p* = .012). As trait extraversion was associated with baseline EBR, we included its interaction with acting condition into a multilevel model to predict the difference in EBR between baseline and T1T2 while also accounting for participants being nested in groups. The model revealed no effect of trait extraversion on EBR change, but significant effects for acting condition. The introversion condition's EBR change was significantly different in contrast to both the extraversion (*B* = 0.272, 95% CI [0.010 – 0.534], *p* = .042) and control condition (*B* = 0.327, 95% CI [0.065 – 0.590], *p* = .015; see Figure 3).

Figure 3

Boxplots of the Mean Eye Blink Rate as a Function of Acting Condition and Time



Note. EBR = spontaneous eye blink rate per minute. T0 = Baseline measurement; T1T2 = mean of the measurements at T1 and T2 (after group discussions). Change in individual scores from T0 to T1T2 is presented as individual dots connected with lines.

Discussion

The current study explored the effects of a manipulation of state extraversion on state PA and EFs. Replicating previous studies, the three acting conditions (extraverted vs. introverted vs. control) had strong effects on state extraversion ratings from all rater perspectives and similar effects on state PA. The change in state PA from baseline to after the discussions was smaller than expected, possibly due to a tendency for preexisting condition differences with unexpectedly lower state PA in the introversion condition (i.e. before participants received acting instructions).

Despite evidence for a successful manipulation of state extraversion/state PA we did not observe any effects of acting condition on EFs as measured with two EF tasks (3-back and switching), and this pattern of null-findings remained consistent across several statistical approaches (multivariate or univariate; mixed model or ANOVA; controlling for the potentially confounding variables task order and time from discussion to EF task). Furthermore, neither state PA nor state extraversion after the discussions, or their interaction with acting condition, explained cognitive performance. This pattern of null-effects could indicate that (1) cognitive performance is rather insensitive towards variation in affective-motivational states. This seems rather unlikely (at least for the switching task) given that there is considerable evidence for the effects of affective-motivational states on stability-flexibility (Dreisbach & Fröber, 2019). It could also indicate that (2) the current manipulation of affective-motivational states was not sufficient to induce changes in cognitive performance, for example because its effects did not last long enough or behavioral instructions were too broad. This implies that the effects of acting condition on cognitive performance might be visible with improvements in study design (for suggestion see section “Limitations and Future Directions”). In addition, the lack of effects of acting condition on cognitive performance could indicate that (3) effects are masked by third variables, such as trait or baseline effects. In the following we address evidence for such trait and baseline effects in the current study.

Somewhat supporting the third interpretation, correlational and exploratory analyses suggested that trait (agentic) extraversion and baseline state PA rather than state measures after the discussions were associated with cognitive performance. Trait extraversion (and its agentic subscale) was associated with slower reactions in the 3-back task and the agentic aspect of extraversion with higher flexibility in the switching task across conditions. Baseline state PA (but not state PA at T1T2) showed an association with higher flexibility in the switching task for the control, but higher stability for the extraversion and introversion condition. Furthermore, trait extraversion and baseline state PA were positively associated.

The association between trait agentic extraversion and higher flexibility across acting conditions mirrors previous findings on the switching task (Herrmann & Wacker, 2021) and is compatible with the hypothesis that, compared to introverts, extraverts have higher flexibility due to a lower updating threshold, possibly due to higher levels in striatal DA (Herrmann & Wacker, 2021). Conversely, the negative association between extraversion and 3-back RT at first glance contradicts the results of previous studies, which found trait extraversion to be associated with better updating performance, either in the form of lower target RTs (Wacker et al., 2006) or higher target accuracy (Herrmann & Wacker, 2021). However, the current results are not directly comparable to these previous studies, because participants of the current study performed a discussion task before completing the EF tasks. The social interaction during the discussion could have activated extraversion-related individual differences in a different way than previous studies using pharmacological manipulations. For example, just being in a group discussion might have prompted more extraverted participants to invest more cognitive resources, potentially leading to decreased performance in the cognitively demanding 3-back task afterwards, but not in the less demanding switching task. This would be compatible with the finding that switching and 3-back measures were uncorrelated in the current study, but not in the only previous study jointly investigating them (Herrmann & Wacker, 2021). In addition, it should be noted that the interpretation of these associations is limited by the fact that they would not survive a rigorous correction for multiple testing.

The fact that we observed associations with switching performance for baseline measurements of PA only, is likely due to these measurements reflecting more stable individual differences in PA. This interpretation is supported by the positive correlation between baseline state PA and trait (agentic) extraversion as well as the observation that the direction of the association between baseline PA and stability-flexibility matched the effect observed for agentic extraversion only in the control but not the acting conditions. Briefly, even though the pattern of findings was different than expected (associations between EFs and PA at baseline rather than at T1T2) it is still compatible with the often-reported effects of positive affective-motivational states on stability-flexibility (Paul et al., 2021). Furthermore, although we did not expect cognitive effects of the current affective-motivational manipulation to be trait-dependent, this finding might be compatible with previous studies reporting trait-dependent cognitive effects of affective manipulations, for example in the context of state/trait positive and negative affect on Stroop performance (Hur et al., 2015). However, interpretation of these findings is again limited by the exploratory nature of these analyses and the absence of rigorous correction for multiple testing.

Effects on Spontaneous EBR

Acting condition affected spontaneous EBR, i.e., a potential indicator of striatal DA activation. The extraversion condition showed a *decrease* in EBR from baseline to after the discussions, which significantly differed from the descriptive *increase* in EBR in the introversion condition. In addition, trait extraversion was negatively associated with EBR at baseline. As both extraversion and EBR are assumed to be associated with higher striatal DA activation (cf. Jongkees & Colzato, 2016; Depue & Collins, 1999), one might expect an EBR increase for the extraversion and a decrease for the introversion condition. However, it remains unclear whether DA activation (and therefore also spontaneous EBR) can be assumed to remain stable during versus after the discussion. For instance, an EBR increase might not indicate high DA activation during the discussion, but instead low DA activation during the discussion with a rebound afterwards. Based on the hypothetical assumption that the EBR reflects striatal DA activation, the current exploratory findings could be taken to indicate that acting condition affected striatal DA activation. However, taken together with the null findings regarding the effects of acting condition on EF tasks, this interpretation should be viewed as preliminary as the pattern of results might also be explained by other, albeit related, processes, such as dopaminergic mechanisms of attentional load and subsequent mental fatigue (Maffei & Angrilli, 2018). Extraverted behavior has already been demonstrated to cause fatigue after a delay of three hours (but not directly afterwards; Leikas & Ilmarinen, 2017), potentially due to higher requirements on self-control and attentional load during the execution of extraverted behavior. EBR changes in the current study could reflect between-condition differences in attentional load, with a lower EBR reflecting higher attentional load carried over from the group discussion (Maffei & Angrilli, 2018). Although this alternative explanation may still involve dopaminergic mechanisms, these could be functionally different from approach- and motivation-related DA activation connected to trait extraversion (Wacker & Smillie, 2015).

Briefly, even though limited by the exploratory character of the current analyses of EBR, the direction of the associations between EBR and both trait and manipulated state extraversion may probably best be taken to indicate that the relationship between EBR and DA activation is (if existent) more complex than previously thought and probably affected by several interacting processes that remain to be elucidated.

Limitations and Future Directions

Despite multiple advantages including a registered and open analysis, sufficient power to find small effects, high reliability of state ratings and EBR, and the application of two EF tasks, the current study also faces several limitations. First, the low reliability of the switching tasks' difference score measure limits the interpretation of both the null-findings and associations observed for this task. As argued before (Herrmann & Wacker, 2021), the switching task was designed with the aim to produce large within-subject effects with little between-subject variation to show consistent condition effects across individuals. Future studies should therefore consider measuring stability-flexibility with tasks better suited to measure individual differences.

Second, the time course of our experimental setup poses the problem that participants completed the EF tasks over 10 minutes after the discussion. It is possible that the positive affective-motivational states induced in the discussion were already attenuated when the EF tasks were completed. As state ratings of behavior and affect during the group discussions were assessed even after each EF task, they might have been confounded by fatigue or biased recall of the group discussion, although this seems unlikely because state ratings still had good to excellent reliability, different rater perspectives highly correlated, and state measures showed significant condition differences in the expected direction. Future studies could still consider replacing mutual state ratings of the participants with ratings of trained raters. The time course of our experimental setup also renders it somewhat unclear whether the changes we found in the EBR after the discussion were caused by a rebound effect or effects of fatigue rather than by direct effects of the experimental manipulation. Future studies might benefit from a measurement right after the discussion without a need for technical installations (e.g. manually counting the EBR from video).

Third, whereas our homogeneous sample of young, healthy, heterosexual participants was necessary to minimize variation in approach motivation during the group discussions and its potential effects on the measures assessed afterwards, it limits generalizability to other populations and contexts with potentially more or less approach motivation. Also, the current study manipulated states only for a short period of time (2x 10 minutes) and it thus remains an entirely open question whether more extensive state manipulations in real-life over several days (cf. Jacques-Hamilton et al., 2018) affects EF performance. For instance, laboratory studies like the present one found positive affective consequences of enacted extraversion irrespective of trait extraversion (Sun et al., 2017), but real-life experience sampling studies found them to partly depend on trait extraversion (Jacques-Hamilton et al., 2018). It further remains unclear whether participants of the control condition acted according to a social norm to contribute to the task (as pointed out by Zelenski et al., 2012). Future studies could profit from applying a study design with trained confederates to attenuate variation in group dynamics (cf. Zelenski et al., 2012).

Finally, just being in a group discussion before completing an EF task might have had effects on task performance we did not control for. Future studies on the cognitive effects of enacted extraversion might benefit from adding a control group which did not partake in any group activity.

Conclusion

The current study is one of the first to investigate the causal effects of enacted extraversion on EFs as an approach to better understand extraversion-EF associations. Despite the clear pattern of differences in positive affective-motivational states, the acting conditions did not produce the expected effects on cognitive performance as suggested by previous studies on extraversion-EF relationships or on effects of affective-motivational states on stability-flexibility. Even though some associations observed between trait extraversion/baseline state PA and cognitive performance in the present study did match these expectations, their interpretation is limited by the exploratory character of these analyses and the low reliability of the switching task measure. In sum, additional work with alternative design features is necessary to further clarify the association between both state and trait extraversion and EFs.

Appendix C

Data Accessibility Statement

We registered[1] methods, hypotheses and analyses on the OSF under https://osf.io/jcuq3/?view_only=e941f9154f6a4747b39db2fb5bfc8ed0 in 2020. The analysis was performed as registered. All non-registered additional analyses are marked as exploratory. Open preprocessed and raw data, codebook, and a supplemental R markdown with complete reproducible analysis code and results (including non-significant effects of models which are only briefly mentioned in the text and parallel sensitivity analyses) can be found online under https://osf.io/gr2bt/?view_only=564a9304fd02473d898612fb06edfdc5. So far there are no other publications based on the current study's dataset.

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[1] The registration was intended to be published before data collection, but was erroneously not submitted. Our registered analysis therefore now primarily serves the purpose of limiting ourselves to a set of a priori defined preprocessing and analysis steps we had decided on before analyzing the data.

References

Baik, S., Yoon, H. S., Kim, S. E., & Kim, S. H. (2012). Extraversion and striatal dopaminergic receptor availability in young adults. *NeuroReport*, *23*(4), 251–254. https://doi.org/10.1097/WNR.0b013e3283507533

Berse, T., Barenberg, J., Urban, V., & Dutke, S. (2014). Agentic extraversion moderates the effect of physical exercise on executive shifting performance. *Journal of Research in Personality*, *52*, 37–41. https://doi.org/10.1016/j.jrp.2014.06.007

Blain, S. D., Sassenberg, T. A., Xi, M., Zhao, D., & DeYoung, C. G. (2021). Extraversion but not depression predicts reward sensitivity: Revisiting the measurement of anhedonic phenotypes. *Journal of Personality and Social Psychology*, *121*(2), e1-e18. https://doi.org/10.1037/pspp0000371

Boot, N., Baas, M., van Gaal, S., Cools, R., & Dreu, C. K. W. de (2017). Creative cognition and dopaminergic modulation of fronto-striatal networks: Integrative review and research agenda. *Neuroscience and Biobehavioral Reviews*, *78*, 13–23. https://doi.org/10.1016/j.neubiorev.2017.04.007

Campbell, A. M., Davalos, D. B., Mccabe, D. P., & Troup, L. J. (2011). Executive functions and extraversion. *Personality and Individual Differences*, *51*(6), 720–725. https://doi.org/10.1016/j.paid.2011.06.018

Chatham, C. H., Herd, S. A., Brant, A. M., Hazy, T. E., Miyake, A., O'Reilly, R., & Friedman, N. P. (2011). From an Executive Network to Executive Control: A Computational Model of the n-back Task. *Journal of Cognitive Neuroscience*, *23*(11), 3598–3619. https://doi.org/10.1162/jocn_a_00047

Chavanon, M.-L., Wacker, J., Leue, A., & Stemmler, G. (2007). Evidence for a dopaminergic link between working memory and agentic extraversion: An analysis of load-related changes in EEG alpha 1 activity. *Biological Psychology*, *74*(1), 46–59. https://doi.org/10.1016/j.biopsycho.2006.07.001

Chavanon, M.-L., Wacker, J., & Stemmler, G. (2013). Paradoxical dopaminergic drug effects in extraversion: dose- and time-dependent effects of sulpiride on EEG theta activity. *Frontiers in Human Neuroscience*, *7*, Article 117, 1–15. https://doi.org/10.3389/fnhum.2013.00117

Cohen, M. X., Young, J., Baek, J.-M., Kessler, C., & Ranganath, C. (2005). Individual differences in extraversion and dopamine genetics predict neural reward responses. *Cognitive Brain Research*, *25*(3), 851–861. https://doi.org/10.1016/j.cogbrainres.2005.09.018

Cools, R. (2019). Chemistry of the Adaptive Mind: Lessons from Dopamine. *Neuron*, *104*(1), 113–131. https://doi.org/10.1016/j.neuron.2019.09.035

Cools, R., & D'Esposito, M. (2011). Inverted-U-shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry*, *69*(12), e113-e125. https://doi.org/10.1016/j.biopsych.2011.03.028

Cooper, A. J., Duke, É., Pickering, A. D., & Smillie, L. D. (2014). Individual differences in reward prediction error: contrasting relations between feedback-related negativity and trait measures of reward sensitivity, impulsivity and extraversion. *Frontiers in Human Neuroscience*, *8*. https://doi.org/10.3389/fnhum.2014.00248

Corr, P. J., & Cooper, A. J. (2016). The Reinforcement Sensitivity Theory of Personality Questionnaire (RST-PQ): Development and Validation. *Psychological Assessment*, *28*(2), 418–427. https://doi.org/10.1037/pas0000273

Costa, P. T., & McCrae, R. R. (1980). Influence of extraversion and neuroticism on subjective well-being: happy and unhappy people. *Journal of Personality and Social Psychology*, *38*(4), 668–678. https://doi.org/10.1037/0022-3514.38.4.668

Dang, L. C., Samanez-Larkin, G. R., Castrellon, J. J., Perkins, S. F., Cowan, R. L., Newhouse, P. A., & Zald, D. H. (2017). Spontaneous Eye Blink Rate (EBR) Is Uncorrelated with Dopamine D2 Receptor Availability and Unmodulated by Dopamine Agonism in Healthy Adults. *ENeuro*, *4*(5). https://doi.org/10.1523/ENEURO.0211-17.2017

Davydenko, M., Zelenski, J. M., Gonzalez, A., & Whelan, D. (2020). Does acting extraverted evoke positive social feedback? *Personality and Individual Differences*, *159*, Article 109883, 1–10. https://doi.org/10.1016/j.paid.2020.109883

Depue, R. A., & Collins, P. F. (1999). Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences*, *22*(3), 491–569. https://doi.org/10.1017/S0140525X99002046

Depue, R. A., & Fu, Y. (2013). On the nature of extraversion: Variation in conditioned contextual activation of dopamine-facilitated affective, cognitive, and motor processes. *Frontiers in Human Neuroscience*, *7*, 288. https://doi.org/10.3389/fnhum.2013.00288

Depue, R. A., Luciana, M., Arbisi, P., Collins, P., & Leon, A. (1994). Dopamine and the Structure of Personality: Relation of Agonist-Induced Dopamine Activity to Positive Emotionality. *Journal of Personality and Social Psychology*, *67*(3), 485–498.

Dreisbach, G., & Fröber, K. (2019). On How to Be Flexible (or Not): Modulation of the Stability-Flexibility Balance. *Current Directions in Psychological Science*, *28*(1), 3–9. https://doi.org/10.1177/0963721418800030

Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K.-P., & Brocke, B. (2005). Dopamine and Cognitive Control: The Influence of Spontaneous Eyeblink Rate and Dopamine Gene Polymorphisms on Perseveration and Distractibility. *Behavioral Neuroscience*, *119*(2), 483–490. https://doi.org/10.1037/0735-7044.119.2.483

Ecker, U. K., Lewandowsky, S., Oberauer, K., & Chee, A. E. (2010). The Components of Working Memory Updating: An Experimental Decomposition and Individual Differences. *Journal of Experimental Psychology: Learning Memory and Cognition*, *36*(1), 170–189. https://doi.org/10.1037/a0017891

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191.

Fleeson, W., & Gallagher, M. P. (2009). The Implications of Big-Five Standing for the Distribution of Trait Manifestation in Behavior: Fifteen Experience-Sampling Studies and a Meta-Analysis. *Journal of Personality and Social Psychology*, *97*(6), 1097–1114. https://doi.org/10.1037/a0016786

Fleeson, W., & Jayawickreme, E. (2015). Whole Trait Theory. *Journal of Research in Personality*, *56*, 82–92. https://doi.org/10.1016/j.jrp.2014.10.009

Fleeson, W., & Jayawickreme, E. (2021). Whole traits: Revealing the social-cognitive mechanisms constituting personality's central variable. In B. Gawronski (Ed.), *Advances in Experimental Social Psychology. Advances in Experimental Social Psychology: Volume 63* (Vol. 63, pp. 69–128). Elsevier. https://doi.org/10.1016/bs.aesp.2020.11.002

Fleeson, W., Malanos, A. B., & Achille, N. M. (2002). An intraindividual process approach to the relationship between extraversion and positive affect: is acting extraverted as "good" as being extraverted? *Journal of Personality and Social Psychology*, *83*(6), 1409–1422. https://doi.org/10.1037/0022-3514.83.6.1409

Fröber, K., & Dreisbach, G. (2014). The differential influences of positive affect, random reward, and performance-contingent reward on cognitive control. *Cognitive, Affective and Behavioral Neuroscience*, *14*(2), 530–547. https://doi.org/10.3758/s13415-014-0259-x

Fröber, K., & Dreisbach, G. (2016). How sequential changes in reward magnitude modulate cognitive flexibility: Evidence from voluntary task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(2), 285–295. https://doi.org/10.1037/xlm0000166

Goldberg, L. R. (1992). The development of markers for the Big-Five factor structure. *Psychological Assessment*, *4*(1), 26–42. https://doi.org/10.1037/1040-3590.4.1.26

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology*, *55*(4), 468–484. https://doi.org/10.1016/0013-4694(83)90135-9

Gratton, G., Cooper, P., Fabiani, M., Carter, C. S., & Karayanidis, F. (2018). Dynamics of cognitive control: Theoretical bases, paradigms, and a view for the future. *Psychophysiology*, *55*(3). https://doi.org/10.1111/psyp.13016

Gray, J. R., & Braver, T. S. (2002). Personality predicts working-memory-related activation in the caudal anterior cingulate cortex. *Cognitive, Affective and Behavioral Neuroscience*, *2*(1), 64–75. https://doi.org/10.3758/CABN.2.1.64

Heller, D., Komar, J., & Lee, W. B. (2007). The dynamics of personality states, goals, and well-being. *Personality and Social Psychology Bulletin*, *33*(6), 898–910. https://doi.org/10.1177/0146167207301010

Herrmann, W., & Wacker, J. (2021). The Selective Dopamine D2 Blocker Sulpiride Modulates the Relationship Between Agentic Extraversion and Executive Functions. *Cognitive, Affective and Behavioral Neuroscience*, *21*(4), 852–867. https://doi.org/10.3758/s13415-021-00887-9

Hur, J., Miller, G. A., McDavitt, J. R. B., Spielberg, J. M., Crocker, L. D., Infantolino, Z. P., Towers, D. N., Warren, S. L., & Heller, W. (2015). Interactive effects of trait and state affect on top-down control of attention. *Social Cognitive and Affective Neuroscience*, *10*(8), 1128–1136. https://doi.org/10.1093/scan/nsu163

Jacques-Hamilton, R., Sun, J., & Smillie, L. D. (2018). Costs and Benefits of Acting Extraverted: A Randomized Controlled Trial. *Journal of Experimental Psychology: General*, *148*(9), 1538–1556. https://doi.org/10.1037/xge0000516

Jongkees, B. J., & Colzato, L. S. (2016). Spontaneous eye blink rate as predictor of dopamine-related cognitive function—A review. *Neuroscience and Biobehavioral Reviews*, *71*, 58–82. https://doi.org/10.1016/j.neubiorev.2016.08.020

Kim, S. H., Hwang, J. H., Park, H. S., & Kim, S. E. (2008). Resting brain metabolic correlates of neuroticism and extraversion in young men. *NeuroReport*, *19*(8), 883–886. https://doi.org/10.1097/WNR.0b013e328300080f

Lai, H., Wang, S., Zhao, Y., Zhang, L., Yang, C., & Gong, Q. (2019). Brain gray matter correlates of extraversion: A systematic review and meta-analysis of voxel-based morphometry studies. *Human Brain Mapping*, *40*(14), 4038–4057. https://doi.org/10.1002/hbm.24684

Leikas, S., & Ilmarinen, V.-J. (2017). Happy Now, Tired Later? Extraverted and Conscientious Behavior Are Related to Immediate Mood Gains, but to Later Fatigue. *Journal of Personality*, *85*(5), 603–615. https://doi.org/10.1111/jopy.12264

Li, M., Wei, D., Yang, W., Zhang, J., & Qiu, J. (2019). Neuroanatomical correlates of extraversion. *NeuroReport*, *30*(14), 953–959. https://doi.org/10.1097/WNR.0000000000001306

Lieberman, M. D., & Rosenthal, R. (2001). Why introverts can’t always tell who likes them: multitasking and nonverbal decoding. *Journal of Personality and Social Psychology*, *80*(2), 294. https://doi.org/10.1037/0022-3514.80.2.294

Luciana, M., Depue, R. A., Arbisi, P., & Leon, A. (1992). Facilitation of Working Memory in Humans by a D2 Dopamine Receptor Agonist. *Journal of Cognitive Neuroscience*, *4*(1), 58–68. https://doi.org/10.1162/jocn.1992.4.1.58

Maffei, A., & Angrilli, A. (2018). Spontaneous eye blink rate: An index of dopaminergic component of sustained attention and fatigue. *International Journal of Psychophysiology*, *123*, 58–63. https://doi.org/10.1016/j.ijpsycho.2017.11.009

Margolis, S., & Lyubomirsky, S. (2020). Experimental manipulation of extraverted and introverted behavior and its effects on well-being. *Journal of Experimental Psychology. General*, *149*(4), 719–731. https://doi.org/10.1037/xge0000668

Mehta, M. A., Manes, F. F., Magnolfi, G., Sahakian, B. J., & Robbins, T. W. (2004). Impaired set-shifting and dissociable effects on tests of spatial working memory following the dopamine D2 receptor antagonist sulpiride in human volunteers. *Psychopharmacology*, *176*(3-4), 331–342. https://doi.org/10.1007/s00213-004-1899-2

Mehta, M. A., Swainson, R., Ogilvie, A. D., Sahakian, J., & Robbins, T. W. (2001). Improved short-term spatial memory but impaired reversal learning following the dopamine D2 agonist bromocriptine in human volunteers. *Psychopharmacology*, *159*(1), 10–20. https://doi.org/10.1007/s002130100851

Miyake, A., & Friedman, N. P. (2012). The Nature and Organisation of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Mueller, E. M., Burgdorf, C., Chavanon, M.-L., Schweiger, D., Wacker, J., & Stemmler, G. (2014). Dopamine modulates frontomedial failure processing of agentic introverts versus extraverts in incentive contexts. *Cognitive, Affective and Behavioral Neuroscience*, *14*(2), 756–768. https://doi.org/10.3758/s13415-013-0228-9

Murdock, K. W., Oddi, K. B., & Bridgett, D. J. (2013). Cognitive Correlates of Personality: Links Between Executive Functioning and the Big Five Personality Traits. *Journal of Individual Differences*, *34*(2), 97–104. https://doi.org/10.1027/1614-0001/a000104

Neo, P. S.-H., McNaughton, N., & Sellbom, M. (2021). Early and late signals of unexpected reward contribute to low extraversion and high disinhibition, respectively. *Personality Neuroscience*, *4*, e5. https://doi.org/10.1017/pen.2021.4

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective and Behavioral Neuroscience*, *12*(2), 241–268. https://doi.org/10.3758/s13415-011-0083-5

O'Gorman, R. L., Kumari, V., Williams, S. C., Zelaya, F. O., Connor, S. E., Alsop, D. C., & Gray, J. A. (2006). Personality factors correlate with regional cerebral perfusion. *10538119*, *31*(2), 489–495. https://doi.org/10.1016/j.neuroimage.2005.12.048

Owen, A. M., Roberts, A. C., Hodges, J. R., & Robbins, T. W. (1993). Contrasting mechanisms of impaired attentional set-shifting in patients with frontal lobe damage or Parkinson's disease. *Brain*, *116*(5), 1159–1175. https://doi.org/10.1093/brain/116.5.1159

Pajkossy, P., Szőllősi, Á., Demeter, G., & Racsmány, M. (2018). Physiological Measures of Dopaminergic and Noradrenergic Activity During Attentional Set Shifting and Reversal. *Frontiers in Psychology*, *9*, 506. https://doi.org/10.3389/fpsyg.2018.00506

Paul, K., Pourtois, G., van Steenbergen, H., Gable, P., & Dreisbach, G. (2021). Finding a balance: modulatory effects of positive affect on attentional and cognitive control. *Current Opinion in Behavioral Sciences*, *39*, 136–141. https://doi.org/10.1016/j.cobeha.2021.03.002

Pizzagalli, D. A., Jahn, A. L., & O'Shea, J. P. (2005). Toward an objective characterization of an anhedonic phenotype: A signal-detection approach. *Biological Psychiatry*, *57*(4), 319–327. https://doi.org/10.1016/j.biopsych.2004.11.026

Seamans, J. K., & Yang, C. R. (2004). The principal features and mechanisms of dopamine modulation in the prefrontal cortex. *Progress in Neurobiology*, *74*(1), 1–57. https://doi.org/10.1016/j.pneurobio.2004.05.006

Sescousse, G., Ligneul, R., van Holst, R. J., Janssen, L. K., Boer, F. de, Janssen, M., Berry, A. S., Jagust, W. J., & Cools, R. (2018). Spontaneous eye blink rate and dopamine synthesis capacity: Preliminary evidence for an absence of positive correlation. *The European Journal of Neuroscience*, *47*(9), 1081–1086. https://doi.org/10.1111/ejn.13895

Smillie, L. D., Cooper, A. J., & Pickering, A. D. (2011). Individual differences in reward-prediction-error: Extraversion and feedback-related negativity. *Social Cognitive and Affective Neuroscience*, *6*(5), 646–652. https://doi.org/10.1093/scan/nsq078

Smillie, L. D., Jach, H. K., Hughes, D. M., Wacker, J., Cooper, A. J., & Pickering, A. D. (2019). Extraversion and reward-processing: Consolidating evidence from an electroencephalographic index of reward-prediction-error. *Biological Psychology*, *146*, 107735. https://doi.org/10.1016/j.biopsycho.2019.107735

Smillie, L. D., Wilt, J. A., Kabbani, R., Garratt, C., & Revelle, W. (2015). Quality of social experience explains the relation between extraversion and positive affect. *Emotion*, *15*(3), 339–349. https://doi.org/10.1037/emo0000047

Steel, P., Schmidt, J., & Shultz, J. (2008). Refining the relationship between personality and subjective well-being. *Psychological Bulletin*, *134*(1), 138–161. https://doi.org/10.1037/0033-2909.134.1.138

Sun, J., Stevenson, K., Kabbani, R., Richardson, B., & Smillie, L. D. (2017). The Pleasure of Making a Difference: Perceived Social Contribution Explains the Relation Between Extraverted Behavior and Positive Affect. *Emotion*, *17*(5), 794–810. https://doi.org/10.1037/emo0000273

Unsworth, N., Robison, M. K., & Miller, A. L. (2019). Individual differences in baseline oculometrics: Examining variation in baseline pupil diameter, spontaneous eye blink rate, and fixation stability. *Cognitive, Affective and Behavioral Neuroscience*, *19*(4), 1074–1093. https://doi.org/10.3758/s13415-019-00709-z

Vaughan, R. S., & Edwards, E. J. (2020). Executive function and personality: The moderating role of athletic expertise. *Personality and Individual Differences*, *161*, 1–7. https://doi.org/10.1016/j.paid.2020.109973

Wacker, J. (2018). Effects of positive emotion, extraversion, and dopamine on cognitive stability-flexibility and frontal EEG asymmetry. *Psychophysiology*, *55(1)*, 1–16. https://doi.org/10.1111/psyp.12727

Wacker, J., Chavanon, M.-L., & Stemmler, G. (2006). Investigating the dopaminergic basis of extraversion in humans: A multilevel approach. *Journal of Personality and Social Psychology*, *91*(1), 171–187. https://doi.org/10.1037/0022-3514.91.1.171

Wacker, J., & Smillie, L. D. (2015). Trait Extraversion and Dopamine Function. *Social and Personality Psychology Compass*, *9*(6), 225–238. https://doi.org/10.1111/spc3.12175

Wacker, J., & Stemmler, G. (2006). Agentic extraversion modulates the cardiovascular effects of the dopamine D2 agonist bromocriptine. *Psychophysiology*, *43*(4), 372–381. https://doi.org/10.1111/j.1469-8986.2006.00417.x

Wallace, D. L., Vytlacil, J. J., Nomura, E. M., Gibbs, S. E. B., & D'Esposito, M. (2011). The dopamine agonist bromocriptine differentially affects fronto-striatal functional connectivity during working memory. *Frontiers in Human Neuroscience*, *5*, 32. https://doi.org/10.3389/fnhum.2011.00032

Wilt, J. A., Bleidorn, W., & Revelle, W. (2017). Velocity Explains the Links between Personality States and Affect. *Journal of Research in Personality*, *69*, 86–95. https://doi.org/10.1016/j.jrp.2016.06.008

Wilt, J. A., Noftle, E. E., Fleeson, W., & Spain, J. S. (2012). The Dynamic Role of Personality States in Mediating the Relationship between Extraversion and Positive Affect. *Journal of Personality*, *80*(5), 1205–1236. https://doi.org/10.1111/j.1467-6494.2011.00756.x

Zelenski, J. M., Santoro, M. S., & Whelan, D. C. (2012). Would introverts be better off if they acted more like extraverts? Exploring emotional and cognitive consequences of counterdispositional behavior. *Emotion*, *12*(2), 290–303. https://doi.org/10.1037/a0025169

Zhang, T., Di, M., Wang, C., Tan, F., Lijun, Z., Jiang, Y., & Li, H. (2015). Dopamine and executive function: Increased spontaneous eye blink rates correlate with better set-shifting and inhibition, but poorer updating. *International Journal of Psychophysiology*, *96*(3), 155–161. https://doi.org/10.1016/J.IJPSYCHO.2015.04.010

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