Individual differences in uncertainty tolerance are not associated with cognitive control functions in the flanker task

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Abstract

Cognitive control refers to the ability to make correct decisions concurrent to distracting information, and to adapt to conflicting stimulus configurations, eventually promoting goal-directed behavior. Previous research has linked individual differences in cognitive control to psychopathological conditions such as anxiety. However, a link with uncertainty tolerance (UT) has not been tested so far, although both constructs describe cognitive and behavioral performance in ambiguous situations, thus they share some similarities. We probed cognitive control in web-based experimentation (jsPsych) with a simple flanker task ($N = 111$) and a version without confounds in episodic memory ($N = 116$). Both experiments revealed two well-established behavioral indices: congruency effects (CEs) and congruency sequence effects (CSEs). Only small-to-zero correlations emerged between CEs, UT, and need for cognitive closure (NCC), a personality trait inversely related to UT. A subtle correlation ($r = .18$) was noted in Experiment 2 between NCC and CSE. Throughout, Bayesian analyses provided anecdotal-to-moderate evidence for the null hypothesis.

Keywords: Cognitive control, uncertainty tolerance, need for cognitive closure, jspsych, flanker effect

Introduction

Irrelevant information can distract goal-directed behavior and requires individuals to focus on relevant stimuli in the environment and to inhibit misleading thoughts and actions. In order to respond correctly, cognitive processes can be flexibly adapted as a function of recent contextual demands. The mechanisms that enable these flexible adaptations are often referred to as *cognitive control* (E. K. Miller & Cohen, 2001) and are, for example, investigated in simple reaction tasks: In the Eriksen flanker task (Eriksen & Eriksen, 1974), for instance, participants are asked to press a left-hand or a right-hand button as fast as possible in response to a central target stimulus (e.g., an arrow pointing to the left or right). Distractors in the display surround this target and these “flankers” can indicate the same response (congruent condition) or a conflicting response (incongruent condition). Importantly, although the flankers are irrelevant to the actual task, incongruent configurations activate the conflicting response to some degree causing *congruency effects* (CE) with longer response times (RTs) and sometimes also more errors in comparison with congruent configurations. Interestingly, after experiencing conflict on incongruent trials, CEs in the following trial are reduced compared to trials following congruent trials (Gratton, Coles, & Donchin, 1992). In the following, we will refer to this behavioral adjustment to ongoing processing demands as the *congruency sequence effect* (CSE; sometimes also referred to as the Gratton effect). The CE and the CSE are thought to reflect the detection of a mismatch between task-relevant and misleading information in a scene (conflict monitoring) and subsequent attentional biasing, for example, by increasing attention to relevant stimulus features or decreasing attention to irrelevant features (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Egner & Hirsch, 2005; Janczyk & Leuthold, 2017; Nigbur, Schneider, Sommer, Dimigen, & Stürmer, 2015; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). The CSE is a reliable behavioral marker for cognitive control and is commonly used to assess individual differences both in healthy and patient populations (Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014b). For instance, individual differences such as action versus state orientation were associated with stronger and weaker CSEs, respectively (Fischer, Plessow, Dreisbach, & Goschke, 2015). In a flanker task with performance-contingent punishment, the CSE was correlated with punishment

sensitivity as captured by the behavioral inhibition scales (Braem, Duthoo, & Notebaert, 2013). CEs were further associated with the personality trait “effortful control”, and subclinical depression and anxiety scores correlated with conflict processing in emotional stimuli (Kanske & Kotz, 2012). Moreover, the conflict elicited by incongruent task conditions was highlighted to be an emotionally aversive signal itself (Dignath & Eder, 2015; Dreisbach & Fischer, 2012; Inzlicht, Bartholow, & Hirsh, 2015).

Cognitive control and psychopathology. Importantly, individual differences in cognitive control in general often comprise a targeted deficit in various mental health conditions such as addiction (Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013), major depression (Clawson, Clayson, & Larson, 2013; Plewnia, Schroeder, & Wolkenstein, 2015), and schizophrenia (Abrahamse et al., 2016; Lesh, Niendam, Minzenberg, & Carter, 2011). Of importance for the present research, performance in the flanker task was also associated with anxiety and depressive symptoms (Larson, Clawson, Clayson, & Baldwin, 2013), and it was suggested that clinical groups may engage further neural circuitry in order to compensate deficient behavioral regulation (Etkin & Schatzberg, 2011; Larson et al., 2013).

Worry, uncertainty tolerance, and psychopathology. An important cognitive precursor of (sub-)clinical anxiety and affective disorders is the emergence and maintenance of excessive worry (Borkovec, Ray, & Stober, 1998; McLaughlin, Mennin, & Farach, 2007). Worrying includes a stream of negative thoughts and images concerned with future events and it is closely related to a personal reluctance of uncertainty. More precisely, intolerance of uncertainty is thought to affect worry directly by drawing attention on worrisome uncertain events, and indirectly by biasing perceptions of actual events and the according recruitment of problem-solving strategies (Ladouceur, Talbot, & Dugas, 1997). Because both excessive worrying and deficient cognitive control were linked to psychological health, we here asked whether individual personality differences in the (in-)tolerance of uncertainty already underlie behavioral differences in cognitive control, as indexed by CE and CSE in the flanker task (Figure 1). In other words, is the tendency to experience contradictory situations as threatening associated with a reduced ability to flexibly adjust cognitive processes?

----- PLEASE PLACE FIGURE 1 ABOUT HERE -----

Cognitive control and uncertainty tolerance: A direct link? However, the mere presence of correlations between two different variables with the same third variable does not necessarily imply that the former two variables are correlated themselves. Here we set out to empirically address the question whether cognitive control and uncertainty tolerance were related. Theoretically, this can be motivated by the revised version of reinforcement sensitivity theory (Corr, 2004; Gray & McNaughton, 2000). According to this theory of individual differences in approach / withdrawal behavior, conflicting information is aversive because of the negative consequences that might follow from underdetermined or ambiguous choices. More specifically, the less

ambiguity-tolerant individuals are, the higher the aversive consequences of ambiguous conflict situations. Behaviorally, this link could be also reflected in according CEs and CSEs. Moreover, in previous research, low and high punishment-sensitive participants differed in their behavioral adaptation to punishment signals (Braem et al., 2013), and conflict monitoring was enhanced by more aversive reinforcement and by higher scores in self-reports of behavioral inhibition (Leue, Lange, & Beauducel, 2012).

Intolerance of ambiguity – as the personality construct was originally framed – describes the mindset and attitude of individuals towards ambiguous stimuli or situations (Frenkel-Brunswik, 1949). Whereas some individuals perceive ambiguous situations as highly aversive events, others experience this lack of decisive information as desirable, challenging, and more interesting. Over the years, the personality variable has been linked with real-world behaviors and traits, such as authoritarianism, creativity, decision-making, cross-cultural competencies, openness-to-experiences, and others (Cools & Van den Broeck, 2007; Furnham & Marks, 2013; Sawyer, 1990). On the other hand, the future-oriented intolerance of uncertainty was linked with making irrational decisions (Luhmann, Ishida, & Hajcak, 2011), vulnerability to excessive worry (Freeston, Rhéaume, Letarte, Dugas, & Ladouceur, 1994; Koerner & Dugas, 2008) as well as depression and anxiety (McEvoy & Mahoney, 2012).

A moderation of uncertainty tolerance (UT) through other cognitive processes has long been hypothesized. For instance, UT has been linked to differences in task effort and engagement (Shaffer, Hendrick, Regula, & Freconna, 1973). The results, however, were largely inconclusive regarding a direct link between cognitive tests and self-report measures (Furnham & Ribchester, 1995).

The present study. Against this background, the current study focuses on the cognitive correlates of UT (Dalbert, 1999) by assessing variability in cognitive control. In order to test sufficiently diverse respondents, we collected data from two samples of volunteers in web-based experimentation, testing two variants of the flanker task. After recording behavioral performance in the respective task, we collected subjective ratings and attitudes towards UT. Furthermore, to cross-validate the expected correlations, we also collected subjective ratings on the need for cognitive closure (NCC), an inversely related concept ($r = -.66$; Schlink & Walther, 2007) that describes individual desires for

definite answers (Schlink & Walther, 2007; Webster & Kruglanski, 1994). Although NCC does not assess the opposite pole of the same dimension as UT but describes another trait variable, individual differences in NCC additional to UT should allow for cross-validation of any anticipated correlation, based on the mutual relation between the two respective questionnaires. Brief scales with good internal consistency [UT: $\alpha = .72$ (Dalbert, 1999); NCC: $\alpha = .78$ (Schlink & Walther, 2007)] are available for both personality measures and – critically – the two constructs make inverse predictions regarding CEs and CSE, drawing on previous research on conflict monitoring and reinforcement sensitivity (Corr, 2004; Leue et al., 2012). For instance, individuals high in uncertainty tolerance (i.e., who like unforeseen surprises and prefer to let things happen) should display smaller CEs and larger regulation capabilities (CSE), given their personal and positive emotional experiences of ambiguity. In contrast, for individuals with increased NCC, who would agree on “having clear rules and order at work is essential to success”, we expected an inverse behavioral pattern with higher influence of interference (larger CE) and less flexibility as evidenced by smaller CSE.

Experiment 1

Methods and Materials

We initially aimed to collect data from a sufficiently large pool of participants to test for medium-sized effects ($|r| > .30$) of UT on behavioral measures of cognitive control (see limitations). A priori power analysis suggested $N = 112$ participants to detect medium-sized effects with a power of 0.9 (at $\alpha = .05$). For flanker effects, web-based experimentation was acceptable, since these behavioral indices are relatively large and stable (van Steenbergen & Bocanegra, 2016) and previous studies detected the RT-based effects in online experiments (Crump, McDonnell, & Gureckis, 2013; de Leeuw & Motz, 2016; Weissman, Jiang, & Egner, 2014).

Participants

The sample was recruited using social networks and mailing lists and full datasets from $N = 113$ volunteers were recorded in Experiment 1. Data from two participants were excluded from all analyses because both participants committed more than 20% errors or trial omissions, thus results are based on the remaining $N = 111$ participants (30

males, ages 19-37 [$M=22.8$ y, $SD=3.3$ y], 8 left-handed). All participants approved online to the informed consent (in accordance with the Declaration of Helsinki) prior to starting the tasks. Finally, after completing the experiment, all participants indicated whether they wanted to transfer their results to the author's server and whether they had thoroughly and honestly completed the tasks and questionnaires (i.e., seriousness-check). In any case, all participants were eligible to enter a lottery and to win an online shop voucher of 20 €.

Experimental software

The experiment was implemented in HTML 5 and JavaScript using libraries from jsPsych 4.3 (de Leeuw, 2015). Recent research demonstrated reliable RT measurements with JavaScript as compared with the MATLAB® Psychophysics Toolbox (de Leeuw & Motz, 2016). Collected data was transferred immediately to the first author's online server after completing the experiment. Participants were redirected to another website if they agreed to disclose their email address for participation in a lottery. This procedure guaranteed that behavioral and questionnaire data were unrelated to the identity of participants.

Questionnaires

Uncertainty tolerance (UT). A brief 8-item questionnaire was administered (Uncertainty Tolerance Scale; German translation by Dalbert, 1999). Items were evaluated on a 6-point scale (e.g., "I like to know what to expect").

Need for cognitive closure (NCC). The 16-item NCC questionnaire assesses individual desires for definite knowledge (German translation by Schlink & Walther, 2007). Items were evaluated on a 6-point scale.

No further questionnaires were assessed in the present study.

Stimuli, procedure, and experimental tasks

After agreeing to the digital informed consent, participants were instructed to respond as fast as possible without errors in the following RT tasks. Questionnaires were answered

upon completion of the behavioral tasks¹ such that self-selection based on UT assessment was reduced and the exhausting part of the study was presented first (i.e., high hurdle; Reips, 2002). Finally, participants affirmed the seriousness-check. Stimuli for the flanker task were left- and right-pointing arrows. A centrally presented arrow indicated the correct keypress, and was flanked by two congruent arrows (<<<<< / >>>>>), or by two incongruent arrows (<<<<< / >>>>>) to its left and right. Responses were given on the 'k'- and 'd'-key. Each trial started with a central fixation dot (500 ms), immediately followed by the stimulus. Responses were allowed for 2000 ms, and immediate feedback was displayed for too slow or wrong responses during an inter-trial interval (ITI) of 500 ms. For correct responses, a blank ITI was displayed for 500 ms. The flanker task consisted of a brief practice block (16 trials) and three experimental blocks with 80 trials each. All four target/flanker combinations were presented 20 times in a random order, resulting in 40 congruent and 40 incongruent trials in each experimental block. After each block participants were provided feedback on the current task progress, mean RT, and number of errors. Participants were asked to respond to the central arrow direction by pressing the left or right response-key as fast as possible without committing much errors.

Data treatment and analysis

For all analyses, trials following an error were excluded. For RT analyses, only correct trials and those with RTs not deviating more than 2.5 *SDs* from the cell means (separately for each participant; 2.6% of all trials) were included. Correct mean RTs and error rates were submitted to repeated measures analyses of variance (ANOVAs) with the factors current congruency (c=congruent, i=incongruent) and preceding congruency (c, i). Further, indices were computed for each participant individually as $CEs = RT_i - RT_c$ and $CSE = (RT_{ci} - RT_{cc}) - (RT_{ii} - RT_{ic})$. Thus, larger CEs indicate more distraction by flanker stimuli, and larger CSE indicates larger adaptations due to the congruency status of the preceding trials. To assess relations between these indices and the questionnaire measures of UT and NCC we computed Pearson correlations. Raw data

¹ For reasons unrelated to this study, we here also recorded participants' performance in a free-choice reaction task consisting of 192 trials. The orders of reaction time tasks and questionnaires (NCC;

can be retrieved from this URL:

https://osf.io/fmqu8/?view_only=398c1e5b4b4743f7af309a7ffca52660.

Data processing and null hypothesis testing was conducted using SPSS, Bayesian analyses were performed using JASP software (JASP Team, 2016).

Results

Questionnaires

Both questionnaires had acceptable internal validity (Cronbach's $\alpha_{UT} = .74$, $\alpha_{NCC} = .79$) and they were inversely correlated (here: $r(109) = -.71$, $p < .001$; cf. Figure 4; see also, Schlink & Walther, 2007). Hence, while both NCC and UT measures approximate individual differences in participants' subjective experience of uncertainty, their correlations with measures of cognitive control (such as the CSE) should differ in sign.

CEs and CSE

Mean RTs (Figure 2, upper-left panel) were slower in incongruent (547 ms) than in congruent trials (452 ms) and the ANOVA showed a significant main effect of current congruency, $F(1,110) = 1294$, $p < .001$, $\eta_p^2 = .92$. There was no significant main effect of previous trial congruency, $F(1,110) = 1.15$, $p = .286$. Furthermore, flanker interference was smaller after incongruent trials (84 ms) than after congruent trials (106 ms), thus pointing to CSE. Accordingly, the interaction of current congruency $\times$ preceding congruency was significant, $F(1,110) = 44.8$, $p < .001$, $\eta_p^2 = .29$. For error rates (Figure 2, bottom-left panel), the main effect of current congruency was also significant, $F(1,110) = 208$, $p < .001$, $\eta_p^2 = .65$, as was the two-way interaction indicating a CSE, $F(1,110) = 34.3$, $p < .001$, $\eta_p^2 = .24$, and flanker interference was smaller after incongruent trials (7.2 %) than after congruent trials (11.1 %). Additionally, a significant main effect of previous trial congruency emerged, $F(1,110) = 38.0$, $p < .001$, $\eta_p^2 = .26$, and participants made more errors after congruent trials (6.5%) than after incongruent trials (4.3%).

UT) were randomized independently across participants. Additional analysis showed no influence of task order on CEs or CSEs in the flanker task, $ps > .51$.

Split-half reliabilities of CE and CSE indices

Reliability of difference scores (CE) and especially of double contrasts (CSE, see formula above) can be low due to several technical reasons, which could diminish correlations of performance indices with questionnaire measures (e.g., J. Miller & Ulrich, 2013). To better evaluate the soundness of assumed correlations, we computed the split-half reliabilities of the CEs and CSE, corrected for full length following Spearman-Brown's formula (and as also implemented in SPSS). Insufficient reliability was detected for CSE in error rates, $r_{1/2}(109) = .045$. However, reliability was acceptable for CSE in RTs, $r_{1/2}(109) = .755$. For CE, good reliability estimates were obtained in both error rates, $r_{1/2}(109) = .854$, and RTs, $r_{1/2}(109) = .867$. Together with the achieved internal reliabilities of the questionnaires, the collected data appeared suitable for the correlation analysis (except for the lack of reliability in errors rates for CSE).

Experiment 1

Simple flanker task (N=111)

Experiment 2

Confound-free flanker task (N=116)

----- PLEASE PLACE FIGURE 2 ABOUT HERE -----

Correlation analysis: Cognitive correlates of uncertainty tolerance?

Indices for CEs and CSEs in the flanker task were computed individually and correlated with UT and NCC scores. Detailed results are displayed in Table 1 and scatter plots are presented in Figure 3. It can be seen that sufficient variation of the behavioral indices and personality traits was present in the sample, but no systematic correlations between the variables were observed. Overall, we observed no significant correlations between UT or NCC and cognitive control in the flanker task as indicated by CEs and CSE (all $|r|s(109) < .106$ and $ps > .268$; see Table 1).

Following this result, we post-hoc decided to conduct additional analyses: First, to draw inferences from the absent correlations, we additionally computed Bayes Factors and posterior probabilities for the null-hypothesis of $p = 0.0$. Second, in a more exploratory approach, we compared the cognitive control indices for extreme groups on the UT and the NCC scales (Supplementary Analysis 1).

----- PLEASE PLACE FIGURE 3 ABOUT HERE -----

Post-hoc Bayesian analysis: Evidence for the null correlations

Bayes analyses and the resulting Bayes Factors (BFs) allow for a more refined and graded evaluation of the evidence for a statistical hypothesis given the data by a

weighted average likelihood ratio. Since positive values are easier to interpret, we here report BF_{01} (as opposed to the more frequently used BF_{10}). If BF_{01} is greater than 1, it indicates evidence in favor of the null hypothesis.

As we were not aware of previous empirical results, we used the default uniform prior distribution on the correlation coefficient ($\beta = 1$) and the JZS Test as recommended by experts and implemented in JASP software (JASP Team, 2016; for more details, see Wagenmakers, Verhagen, & Ly, 2016; Wetzels & Wagenmakers, 2012) to calculate the BFs. Thus, we assigned equal a priori probabilities to any correlation coefficients. The resulting BFs are provided in Table 1, and we obtained moderate evidence (all $BF_{01} > 4.6$) in favor of all null-hypotheses (Jeffreys, 1961) related to the reported correlations. Finally, BFs also allow for a calculation of the posterior probability of the null or alternative hypothesis, that is: how probable is the hypothesis of a correlation, given the collected data (Edwards, Lindman, & Savage, 1963; Masson, 2011). Such calculation is dependent on the prior probabilities for null and alternative hypotheses, which were assumed equally likely due to the lack of previous empirical evidence. All single probabilities are reported in Table 1. At the minimum, the probability of a null correlation was $p_{posterior}(H_0) = .821$ (for the link between NCC and CSE in error rates) and above $p_{posterior}(H_0) = .873$ for the remaining correlations.

Experiment 2

The interpretation of CSEs as resulting from flanker and other simple conflict tasks has been criticized because of confounds for the critical trial transitions driven by episodic memory traces involving full repetitions, partial repetitions, or full alternations of stimulus-response episodes (e.g., Mayr, Awh, & Laurey, 2003). Thus, improved versions were developed as a consequence that allow to better control for such confounds (e.g., see Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014a for a review). Experiment 2 used such a confound-free variant of the flanker task with full feature alternations on every trial by drawing on two distinct stimulus and response sets (Schmidt & Weissman, 2014; Weissman et al., 2014).

Methods and Materials

Participants

Another sample of $N = 116$ volunteers was recruited for this experiment (34 males, ages 36-75 [$M = 42.6$ y, $SD = 6.0$ y], 10 left-handed), data from two additional participants were unusable (no correct responses). All participants approved the informed consent before starting the tasks. In this form, participants also confirmed that they had not participated in the experiment before.

Experimental software

Identical to Experiment 1.

Questionnaires

Identical to Experiment 1. For exploratory purposes, we also collected responses on the patient-health-questionnaire (PHQ-9), which are reported on in the supplementary material (Supplementary Table 1). No further questionnaires were assessed in the present study.

Stimuli, procedure, and experimental tasks

The general procedure was identical to Experiment 1, except for the confound-free flanker task. We implemented the task as introduced by Weissman et al. (2014) in jsPsych and describe the most important features here.

Stimuli for the confound-free flanker task were the letters A, B, Y, and Z, which were assigned to left- and right-hand index- and middle-finger key presses (keys: d, f, k, and l). An additional practice block of 20 trials trained the four letter-key assignments along with respective feedback and continuous presentation of the mapping. Another practice block of 17 trials consisted of the confound-free flanker task, which was followed by 4 test blocks of each 97 trials.

Two sets of stimulus-response combinations were created and each trial-transition alternated between those two sets, avoiding memory-driven confounds. Six identical flankers of the same set were presented left and right to the target. Fully balanced transition sequences were determined in predefined lists based on Euler paths. To augment CSEs, trial structure was a sequence with 133 ms presentation of only the flankers without target, a 33 ms blank ITI, and 133 ms presentation of both flankers and the target (Weissman et al., 2014). After each block, participants were provided

feedback on the current task progress, mean RT, and number of errors. Participants were asked to respond to the central letter identity by pressing the correct response-key as fast as possible without committing much errors.

Data treatment and analysis

Statistical analyses were performed analogous to Experiment 1. Moreover, combined data from both experiments were probed for the hypothesized correlations (Supplementary Table 2).

Results

Questionnaires

Both questionnaires had acceptable internal validity ($\alpha_{UT} = .72$, $\alpha_{NCC} = .80$) and they were inversely correlated ($r(114) = -.45$, $p < .001$, see Figure 4).

----- PLEASE PLACE FIGURE 4 ABOUT HERE -----

CEs and CSE

Mean RTs (Figure 2, upper-right panel) were slower in incongruent (646 ms) than in congruent trials (560 ms) and the ANOVA showed a significant main effect of current congruency, $F(1,115) = 636$, $p < .001$, $\eta_p^2 = .85$. Furthermore, flanker interference was smaller after incongruent trials (66 ms) than after congruent trials (107 ms), thus

pointing to CSE without memory confounds. Accordingly, the interaction of current congruency $\times$ preceding congruency was significant, $F(1,115) = 137$, $p < .001$, $\eta_p^2 = .54$. There was also a main effect of preceding congruency, $F(1,115) = 30.4$, $p < .001$, $\eta_p^2 = .21$, with 9 ms slower responses after incongruent than after congruent trials. For error rates (Figure 2, bottom-right panel), the main effect of current congruency was also significant, $F(1,115) = 28.0$, $p < .001$, $\eta_p^2 = .20$, as was the two-way interaction indicating a CSE without memory confounds, $F(1,115) = 10.9$, $p < .001$, $\eta_p^2 = .09$. Additionally, a significant main effect of previous trial congruency emerged, $F(1,115) = 54.6$, $p < .001$, $\eta_p^2 = 0.32$, and participants made more errors after congruent trials (7.8%) than after incongruent trials (6.2%).

Split-half reliabilities of CE and CSE indices

Globally, split-half reliabilities of the memory confound-free flanker task variant were slightly lower than for the variant used in Experiment 1. For the CE, a good reliability was observed in RTs, $r_{1/2}(114) = .855$, but reliability was reduced in error rates, $r_{1/2}(114) = .622$. For CSE, reliability in RTs was observed at $r_{1/2}(114) = .622$. Comparable to Experiment 1, split-half reliability of CSE in error rates was insufficient, $r_{1/2}(114) = .012$.

Correlation analysis: Cognitive correlates of uncertainty tolerance?

Indices for the CEs and the CSEs in the flanker task were computed individually and correlated with UT and NCC scores. Detailed results are displayed in Table 1 and scatter plots are presented in Figure 5. Overall, we observed no significant correlations between UT or NCC and cognitive control in the flanker task as indicated by CEs (all $|r|s(114) < .021$ and $ps > .825$; see Table 1).

In contrast to Experiment 1, however, CSE in RTs were negatively related to NCC ($r(116) = -.182$, $p = .051$), and correlations between the memory-confound free CSE with UT and NCC were slightly larger in this Experiment 2 compared to Experiment 1, although posterior probabilities from the Bayesian correlation analyses were not presenting substantial evidence for either the null or alternative hypothesis in this case.

----- PLEASE PLACE FIGURE 5 ABOUT HERE -----

----- PLEASE PLACE TABLE 1 ABOUT HERE -----

Comparison of correlations between CSE in RT and NCC in Experiments 1 and 2

To address somewhat conflicting results between Experiments 1 and 2 on a correlation between NCC and CSE in RTs, we also directly compared these two correlation coefficients. In particular, correlation coefficients were z-transformed and submitted to a Z-test for independent samples. The difference between correlations was not significant, $z = 1.79$, $p = .074$.

Discussion

Summary of results. In the present study, we investigated links between two established indices of cognitive control (CEs and CSEs in the flanker task) with the personality measures of uncertainty tolerance (UT) and need for cognitive closure (NCC). First of all, the results replicate several previous observations, reaffirming that the internet-based data collection did produce valid data. In particular, the flanker task itself produced substantial and reliable CEs and CSEs (Duthoo et al., 2014b; Gratton et al., 1992), at least in RTs. The same was true for the memory confound-free variant in Experiment 2, as expected from previous observations in different online and offline settings (Schmidt & Weissman, 2014; Weissman et al., 2014). Also, an inverse relationship between UT and NCC was replicated in both experiments (Dalbert, 1999; Schlink & Walther, 2007).

However, in contrast to our hypotheses, we did not observe positive evidence for correlations between cognitive control with UT and NCC. Using (post-hoc) Bayes analyses, we quantified the evidence for the null-hypothesis of no relationship between UT, CE, and CSE as moderate. Similarly, moderate evidence emerged against correlations between the examined indices of cognitive control with the (inversely related) personality construct of NCC in Experiment 1, but not in Experiment 2. In the latter, we observed a marginally significant correlation in the expected direction, but Bayesian analysis still rather supported the null than the alternative hypothesis to an anecdotal degree. Furthermore, the correlation would only explain 3.3 % of variance in CSE. Nevertheless, these differential results were also corroborated by post-hoc extreme group analyses (Supplementary Analyses 1-2).

Limitations of the study. Flanker tasks are widely accepted tools for studying cognitive control functions. Nevertheless, other behavioral tasks may require slightly different implementations of cognitive control that could also better reflect the affective connotations of UT (and worry). For instance, a study by Dignath and Eder (2015) showed that stimulus conflict induced by Stroop stimuli causes a motivational tendency to avoid the stimulus (see also Dignath, Kiesel, & Eder, 2015). This is in line with recent evidence that conflict in the Stroop task is negatively evaluated (Dreisbach & Fischer, 2012; see also Inzlicht et al., 2015). Furthermore, conflict-specific control processes may differ for various conflict tasks such as the Stroop, Eriksen flanker, SNARC, and Simon task (Egner, 2008; Schroeder, Pfister, Kunde, Nuerk, & Plewnia, 2016; Soutschek, Müller, & Schubert, 2013), and also for different emotional and non-emotional stimulus components (Dignath, Janczyk, & Eder, 2017; Kanske & Kotz, 2012; Soutschek & Schubert, 2013). Likewise, results of Experiment 2 may suggest that memory confound-free measures of conflict regulation could be better suited to reveal effects which would be otherwise concealed by unwanted influences of episodic memory retrieval or contingency learning.

Similar to the behavioral tasks, slightly different variants also of the concept of UT exist in contemporary research (Dalbert, 1999; Furnham & Marks, 2013). Particularly interesting might be the distinction between inhibitory and prospective features of UT. In a recent study, the error-related negativity component of event-related potentials elicited by the flanker task was positively and negatively correlated with inhibitory and prospective UT components, respectively (Jackson, Nelson, & Hajcak, 2016). A relation of these UT components with CE and CSE was not tested, however. Nevertheless, even if such a link existed, the present results would corroborate a certain task-specificity and thus warrant limited prevalence of such a correlation. In this respect, our results are consistent with accumulating evidence that self-report measures and laboratory assessments of self-control are often not highly correlated (Cyders & Coskunpinar, 2012; Stahl et al., 2014).

Our initial power analysis may have been too optimistic when considering that average effect sizes in psychology are smaller than moderate according to recent meta-analyses suggesting $|r| = .21$ (Lakens & Evers, 2014; Richard, Bond, & Stokes-Zoota, 2003). If

assuming this effect size, of course, the power of our experiments was smaller in comparison with the one we assumed for our power calculations. Yet, Bayesian analyses nevertheless are in favor of null effects in both experiments regarding correlations between CE with UT or NCC. Further, if one agrees that both flanker tasks assess the same construct, combined analyses further support our conclusions of non-significant correlations despite the higher statistical power (total N = 227; see Supplementary Table 2).

Conclusion. Empirically and theoretically, UT was previously associated with clinical characteristics such as the development and maintenance of worries (Freeston et al., 1994). Thus the concept presents a considerable component of general anxiety disorder and depression (Dugas, Gagnon, Ladouceur, & Freeston, 1998; McEvoy & Mahoney, 2012). Great interest is currently also invested on the characterization of cognitive control deficits in psychopathology (Goschke, 2014; Plewnia et al., 2015). By investigating the correlations between the two variables directly, we empirically tested whether they were indicative of shared processes. In this respect, our results may suggest that distinct vulnerability factors are captured by UT and cognitive control functions. Alternatively, it may be possible that smaller links can be detected in other conflict tasks (e.g., with emotional stimuli), in other populations, or by assessing prospective and inhibitory UT separately. In conclusion, results from the present study suggest that UT and cognitive control functions are not directly related to each other. Future research could assess whether this generalizes to other conflict tasks as well.

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Tables and Figure Captions

Table 1. Correlations between cognitive control measures and personality traits. Indices from RT and error rates were computed individually and correlated with scores of the Need for Cognitive Closure and Uncertainty Tolerance scales (Pearson's *r*). In addition, Bayes Factors and posterior probabilities were computed for quantification of evidence in favor of the null hypothesis, assuming equal prior probabilities of *H*₀ and *H*₁ due to the lack of prior empirical evidence.

Cognitive control measure	Need for Cognitive Closure				Uncertainty Tolerance			
	<i>r</i>	<i>p</i>	BF ₀₁	<i>p</i> (<i>H</i> ₀ <i>D</i>)	<i>r</i>	<i>p</i>	BF ₀₁	<i>p</i> (<i>H</i> ₀ <i>D</i>)
Experiment 1 (simple arrow flanker task variant; N=111)								
RT								
Congruency effect	.022	.821	8.22	.892	.028	.769	8.07	.890
Congruency-sequence effect	.057	.550	7.07	.876	.056	.562	7.14	.877
Error rates								
Congruency effect	-.062	.520	6.87	.873	.059	.540	7.00	.875
Congruency-sequence effect	.106	.268	4.60	.821	-.055	.566	7.16	.877
Experiment 2 (flanker task variant without memory confounds; N=116)								
RT								
Congruency effect	.021	.825	8.41	.894	.005	.958	8.60	.896
Congruency-sequence effect	-.182	.051	1.31	.567	.094	.314	5.22	.839
Error rates								
Congruency effect	-.020	.835	8.43	.894	.013	.894	8.54	.895
Congruency-sequence effect	-.085	.367	5.76	.852	-.133	.156	3.18	.761

Figure 1. Empirical and hypothesized relationships between personality and behavioral measures. *Uncertainty tolerance is thought to precede worrying and emergence of anxiety. Cognitive control is thought to impact various psychopathological conditions including anxiety. To probe a potential direct link between uncertainty tolerance and cognitive control empirically, we here collected performance on two behavioral indices of cognitive control (CE and CSE) and two self-report measures (UT and NCC).*

Figure 2. Mean RTs and error percentages (PEs) s as a function of current and previous trial congruency in Experiments 1 and 2.

Figure 3. Scatter plots of UT scores and CEs (left panel) and CSE indices (right panel) in responses times (top row) and error rates (bottom row) [Experiment 1].

Figure 4. Correlation between UT and NCC in Experiments 1 and 2.

Figure 5. Scatter plots of UT scores and CEs (left panel) and CSE indices (right panel) in responses times (top row) and error rates (bottom row) [Experiment 2].