Title: The interplay of trait worry and trait anxiety in determining episodic retrieval: the role of cognitive control

Authors's Manuscript

Péter Pajkossy [a, b], Attila Keresztes [c], and Mihály Racsmány [a, b]

[a] Hungarian Academy of Sciences, Neurocognitive Disorders of the Frontostriatal System Research Group

[b] Department of Cognitive Science, Budapest University of Technology and Economics, Budapest, Hungary

[c] Max Planck Institute for Human Development, Berlin, Germany

Short title: Worry, Anxiety, and Episodic Retrieval

This work was supported by the KTIA NAP Grant (ID: 13-2-2014-0020). The preparation of the paper was also supported by the Early Carrier Stimulus Award rewarded to the first author by The European Society for Cognitive Psychology.

Correspondence concerning this article should be addressed to Péter Pajkossy.

Email: ppajkossy@cogsci.bme.hu;

Abstract

Worrying is a key concept in describing the complex relationship between anxiety and cognitive control. On the one hand, cognitive control processes might underlie the specific tendency to engage in worrying (i.e. trait worry), conceptualized as a future-oriented mental problem-solving activity. On the other hand, the general tendency to experience the signs and symptoms of anxiety (i.e. trait anxiety) is suggested to impair cognitive control because worrisome thoughts interfere with task-relevant processing. Based on these opposing tendencies, we predicted that the effect of the two related constructs, trait anxiety and trait worry, might cancel out one another. In statistics, such instances have been termed suppressor situations. In four experiments, we found evidence for such a suppressor situation: when their shared variance was controlled, trait worry was positively whereas trait anxiety was negatively related to performance in a memory task requiring strategic, effortful retrieval. We also showed that these opposing effects are related to temporal context reinstatement. Our results suggest that trait worry and trait anxiety possess unique sources of variance which differently relate to performance in memory tasks requiring cognitive control.

Keywords: worry, cognitive control/executive functions, episodic memory, suppressor situation, context reinstatement;

The interplay of trait worry and trait anxiety in determining episodic retrieval: the role of cognitive control

Worry is a form of future-oriented thinking about possible threatening events, involving predominantly verbal-linguistic thought (Borkovec, Robinson, Pruzinsky, & DePree, 1983, Sibrava & Borkovec, 2006). It is present in many mood and anxiety disorders (Purdon & Hardington, 2006), and is a core feature of Generalized Anxiety Disorder (GAD, American Psychiatric Association, 2013). Besides, it is also a key concept in understanding the complex relationship between anxiety and a diverse set of cognitive processes, which control and organize subordinate-level processing. These processes, called executive functions or cognitive control processes, are associated with mental effort, conscious attention and prefrontal cortex activity (e.g. Baddeley, 1996; Engle, 2002, Smith & Jonides, 1999).

On the one hand, several theoretical accounts and empirical results suggest, that cognitive control processes might underlie the tendency to worry (i.e. trait worry). Some investigators, for example, termed anxiety the "shadow of intelligence", because cognitive processes linked to cognitive control, such as prospection, planning and problem-solving, might underlie anxious experience in general, and worrying in particular (Barlow, 2002; Liddell, 1949). In a similar way, Borkovec et al. (1983, p. 10) defined worry as a "mental problem-solving activity designed to prevent the occurrence of traumatic future events". Moreover, Price and Mohlman (2007) suggested that cognitive control processes might enable participants to selectively focus on abstract verbal-linguistic worries and inhibit threat-related mental imagery, contributing to cognitive avoidance, an important feature of worrying (see e.g. Sibrava & Borkovec, 2006). Furthermore, Dash, Meeten and Davey (2013) proposed that worrying can be related to intensive, effortful elaboration of information, called systematic information processing, involving analytic and verbally-based thought processes. Finally, empirical evidence also links worrying and GAD to enhanced cognitive performance (Coplan et al., 2010; Mueller, Nguyen, Ray, & Borkovec, 2010; Perkins & Corr, 2005), to mental effort (Verkuil, Brosschot, Borkovec, & Thayer, 2009) and to overactive regions or increased volume of the prefrontal cortex (Hoehn-Saric, Lee, McLeod, &Wong, 2005; Matthew et al., 2004; Mohlman, Price, Eldreth, Chazin, Glower, & Kates, 2009).

On the other hand, the general tendency to experience the various signs and symptoms of anxiety (i.e. trait anxiety, see Spielberger, 1975) is suggested to impair cognitive control because it is associated with the preferential processing of worrisome thoughts or threatening stimuli (e.g. Eysenck & Calvo, 1992; Eysenck, Derakshan, Santos, & Calvo, 2007, Zeidner, 1998) and because worrying during a cognitive task consumes the very same processing resources that are used to maintain task-relevant processing (e.g., Eysenck & Calvo, 1992; Hayes, Hirsch, & Mathews, 2008; Rapee, 1993). The most recent and comprehensive formulation of this claim is the attentional control theory (Eysenck et al., 2007), which states that anxiety impairs cognitive control processes by reducing attentional focus, because "anxious individuals preferentially allocate attentional resources to threat-related stimuli whether internal (e.g., worrisome thoughts) or external (e.g., threatening task-irrelevant distractors)" (Eysenck et al., 2007, p. 18).

The Interplay of Trait Worry and Trait Anxiety – a Suppressor Situation

Based on the above, trait worry should be positively, whereas trait anxiety should be negatively related to performance in tasks requiring cognitive control. The two constructs, however, are strongly correlated (see e.g. Startup & Erickson, 2006), thus they might cancel out or weaken each other's effect on cognitive control. This paradoxical phenomenon is called suppression (Cohen, Cohen, West, & Aiken, 2003; Conger, 1974; Horst, 1941), or a suppression/suppressor situation (Paulhus, Robins, Trzesniewski, & Tracy, 2004;Tzelgov & Henik, 1991) and can be demonstrated in regression models with more than one predictor in all cases where "the relationship between the independent or causal variables is hiding or suppressing their real relationship with Y [the criterion variable], which would be larger or possibly of opposite sign were they not correlated" (Cohen et al., 2003, p. 78).

Evidence for such a suppressor situation comes from studies showing that the statistical control of trait anxiety is required to demonstrate that worry is associated with enhanced cognitive performance (Pajkossy, Dezső, & Paprika, 2009; Siddique, LaSalle-Ricci, Glass, Arnkoff, & Díaz, 2006) and with problem-focused coping (Davey, Hampton, Farrell, & Davidson, 1992). To the best of our knowledge, however, no study has yet investigated systematically how the two opposing tendencies relating cognitive control to trait anxiety and trait worry, respectively, interact to yield a suppressor situation. Thus, the aim of our research was to find further evidence for the link between trait worry and cognitive control and to test for the presence of a suppressor situation.

Due to high levels of multicollinearity (i.e. highly correlated predictors), suppressor situations are prone to provide unreliable effects with only small changes in the data yielding large changes in the results (Lynam, Hoyle, & Newman, 2006; Tzelgov &Henik, 1991). To avoid this, two precautionary measures were taken in designing our research: First, we followed the advice of Tzelgov and Henik (1991) to carefully replicate suppressor situations. Second, besides showing a suppressor situation with a task requiring cognitive control we also aimed to show the lack of a suppressor situation using a control task, which resembled the first task to the closest possible degree, but did not require cognitive control.

To this end, we tested the hypothesized suppressor situation using tasks of an information processing domain in which cognitive control is involved in some but not all aspects of performance: episodic memory retrieval.

The Role of Cognitive Control in Episodic Retrieval

Episodic retrieval refers to our ability to recollect and reconstruct details of personally experienced past events (Conway, 2009; Tulving, 1983). It is directed by retrieval cues which interact with the previously stored memory representation to trigger recall (Conway & Pleydell-Pearce, 2000; Moscovitch, 1994).

Cognitive control processes might support the retrieval process to different degrees depending on the accessibility of cues during retrieval. On the one hand, in cases of environmentally-cued retrieval, when the retrieval cue is present in the environment, available to the individual, and there is a strong association between cue and the target memory, cognitive control might not be essential for successful retrieval. Such a situation is modelled in cued recall or in recognition tests. On the other hand, in cases of self-cued retrieval, details of past experience have to be retrieved without any external cue, as modelled in free recall tasks. This requires cognitive control to start an effortful search process, whereby individuals generate potential retrieval cues and monitor the effectiveness of these cues in accessing the memory representation (Brand & Markowitsch, 2008; Conway & Pleydell-Pearce, 2000; Moscovitch, 1994; Petrides, 1996).

A crucial component of this controlled search might be the reinstatement of temporal context: items are associated with the gradually changing internal context during encoding, and this internal context is reinstated during retrieval to produce retrieval cues (see e.g. Sederberg, Howard, & Kahana, 2008). The role of temporal context reinstatement in free recall is evidenced by the contiguity effect: items studied in temporal proximity tend to be recalled successively (Kahana, 1996).

The Current Research

Based on the above, our research had two main hypotheses: First, motivated by theoretical considerations (e.g. Barlow, 2002; Dash et al, 2013) and empirical findings (e.g. Coplan et al, 2010; Mueller et al, 2010), we predicted that trait worry will be associated with good cognitive control abilities and thus with good performance in episodic memory tasks requiring self-cued retrieval (Hypothesis 1). Second, we expected to observe a suppressor situation and predicted that controlling for the shared variance of trait anxiety and trait worry will increase or even reveal the positive link between trait worry and self-cued retrieval and the negative link between trait anxiety and self-cued retrieval (Hypothesis 2). In tasks requiring environmentally-cued retrieval, which are not exclusively reliant on cognitive control processes, these effects were not expected.

To test these hypotheses, we conducted a set of four studies. Self-cued retrieval was assessed by a free recall task in all four studies, whereas environmentally-cued retrieval was assessed by a recognition task in Study 1, 2, 4 and by a cued recall task in Study 3. This latter was a paired-associate learning task: participant learnt word-pairs and then were presented with one word (cue-word) and were required to name its pair (target-word). To increase the validity and reliability of our memory measures, in Study 4, both the free recall and the recognition task was assessed three times. Finally, we also conducted additional post-hoc analyses, in which data from the four studies were combined.

To minimize potential confounding effects, we included several control variables. First, because women are associated with higher levels of anxiety and worry (Holaway, Rodebaugh, Heimberg, 2006), and with better episodic memory performance (Herlitz, Nilsson, & Baeckman, 1997), the possible mediator role of gender was controlled for in all four studies. Second, because worrying is related to perfectionism (Stöber & Joormann, 2001), which is associated with striving and enhanced motivation to perform well in laboratory tasks (Stöber & Otto, 2006) we included a relevant facet of perfectionism (high personal standards) as a control variable, using a questionnaire in Study 2. Besides, we also measured the time participants spent on the self-paced memory tasks in Study 2-3, and we assessed their subjective estimate of retrieval effort and interference in Study 4. Third, because its assumed central and causative role in the link between anxiety and cognition (Eysenck et al., 2007; Zeidner, 1998), in Study 2, we measured the level of current, experienced anxiety (i.e. state anxiety, Spielberger, 1975). Finally, to ensure that the link between trait worry and self-cued retrieval does not depend solely on the verbal nature of the to-be-learned material, in Study 2, we used pictorial stimuli (faces of famous actors).

Study 1

In Study 1, self-cued retrieval was assessed by a free recall task, whereas environmentally-cued retrieval was assessed by a recognition task.

Method

Participants. Data were collected from 94 participants recruited from the Budapest University of Technology and Economics. They participated for partial credit in introductory psychology courses. Two of them were excluded due to random responding in the recognition task, thus data from 92 participants, 44 female, M_{age} = 21.79 years, *SD* = 2.07, range = 19-32, were analysed.

Material. Trait anxiety was assessed by the Trait subscale of the State-Trait Anxiety Inventory, Form X (STAI-T; Spielberger, Gorsuch, & Lushene, 1970; Hungarian version: Sipos & Sipos, 1983), assessing the tendency to experience the physiological and psychological signs of anxiety. The inventory consists of 20 items, and response to each item is given on a four point scale ranging from 1 (*not at all typical*) to 4 (*very typical*).

To assess trait worry, we used the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990; Hungarian version: Pajkossy, Simor, Szendi, & Racsmány, in press), which measures the general tendency toward frequent and excessive worry characteristic of GAD. The PSWQ consists of 16 items, and each item is scored on a five point scale ranging from 1 (*not at all typical*) to 5 (*very typical*).

The stimuli for the recognition tasks were presented using Presentation® software (Version 14.3, www.neurobs.com). For the memory tasks, we selected 48 moderately frequent nouns based on a Hungarian word frequency norm (Kónya & Pintér, 1985), and created four separate lists.

Design. We presented each participant with one list selected at random from the four different lists. To avoid carry-over effects, we varied task type between subjects (i.e., a between-subject design): 48 participants, 25 female, M_{age} = 21.73 years, *SD* = 2.20, range = 19–32, completed the free recall task (recall group), whereas 44 participants, 18 female, M_{age} = 21.69, *SD* = 1.96, range = 19–27, completed the recognition task (recognition group).

Procedure. Participants were tested individually in a laboratory setting. Each word was displayed on a computer screen for two seconds with a one second inter-item interval. Participants were instructed to memorise the words. Words of a given list were presented in the same order in each instance. Following this, simple mathematical problems were solved for 8 minutes. Thereafter, we asked participants in the recall group to write down the previously presented words on a sheet of paper, whereas participants in the recognition group saw all 48 words sequentially on a computer screen and had to indicate with a key-press whether a given item had been presented during learning or not. The order of presentation during the recognition task was the same for all participants. No time constraints were imposed for the memory tasks, either in this or in the subsequent studies. After completing the memory task, participants filled out the questionnaires and were debriefed.

Data analysis. Free recall performance was measured by recall percentage, whereas for the recognition task, recognition sensitivity index (*d'*) was calculated from hit and false alarm rates.

To test our hypothesis, a series of hierarchical linear regression analyses were run, with recall percentage and recognition sensitivity as criterion variables. In Step 1a and 1b, the criterion variables were regressed separately on STAI-T and PSWQ, respectively. In Step 2, STAI-T and PSWQ were entered together into the regression model. Because multiple regression analysis reveals the partial effects of the predictor variables, entering STAI-T and PSWQ together enabled us to investigate their independent effect with the shared variance partialed out.

Mackinnon, Krull, and Lockwood (2000) showed that testing a suppressor effect is mathematically equivalent to the testing of a mediator effect, thus its statistical analysis is also similar. The change in the predictor's effect on the criterion caused by accounting for the mediator/suppressor variable is estimated, and the indirect effect of the predictor on the criterion *through* the mediator is calculated. We report the indirect effects associated with the anxiety measures, for both recognition and free recall performance, as criterion. We used the method suggested by Preacher and Hayes (2008), which applies bootstrapping to estimate the indirect effect and its 95% confidence interval (CI). To compare indirect effects, we also report a scale-independent effect size measure, the completely standardized indirect effect index (Preacher & Kelley, 2011).

Given the fact that participants learned different word lists, their memory performance might have been determined to some extent by differences between the relative difficulties of the four lists. The variables representing memory performance might therefore be clustered, which would violate the non-independence of observations assumption of ordinary least squares regression. To correct for this, following the advice of Cohen et al. (2003), we incorporated the clustered structure into the model in Step 3, by entering PSWQ and STAI-T together with three dummy variables representing the list learned by the individual participant. Another dummy variable was entered to control for the possible mediator role of gender.

The distribution of recall percentage was skewed, resulting in non-normal distribution and heteroscedasticity of the regression residuals. We thus felt it appropriate to use log-transformed values of recall percentage in all analyses.

We also looked at the Variance Inflation Factors indexing the levels of multicollinearity: in none of the multiple regression models of Study 1-4, did its level exceed four. Because only values above 10 are regarded problematic (Cohen, 2003), we suggest that high collinearity was not a problem in our analyses.

Results and Discussion

Descriptive statistics related to memory performance, PSWQ, and STAI-T are presented in Table 1. Trait worry and trait anxiety were correlated in both groups (recall group: $r = .75$, $p < .001$; recognition group: $r = .83$, $p < .001$).

(Table 1 about here)

The first two steps of the hierarchical regression analysis are shown in Table 2. In the recall group, supporting Hypothesis 1, higher levels of trait worry predicted better free recall performance (Step 1b: $\beta = .29$, $p < .048$). The predictions of Hypothesis 2, however, were only partially confirmed: controlling the shared variance of trait worry and trait anxiety in Step 2 significantly altered the effect of trait anxiety (Step 1a: $\beta = .12$; Step 2: $\beta = -.21$; standardized indirect effect through trait worry: .33, 95% CI [.02, .65]), but not the effect of trait worry (Step 1b: $\beta = .29$; Step 2: $\beta = .45$; standardized indirect effect through trait anxiety: -.16, 95% CI [-.55, .16]) on recall percentage. Moreover, these results must be interpreted with some caution due to insufficient model-fit, $F(2, 45) = 2.57$, $p = .09$. The regression coefficients, however, remained unchanged in Step 3 (trait anxiety: $B = -0.006$, $SE_B = 0.005$, $\beta = -.24$, $p = .23$; trait worry: $B = 0.007$, $SE_B = 0.003$, $\beta = .43$, $p = .03$), where accounting for the recall effects of list-difficulty improved model-fit, $F(6, 41) = 3.08$, $p = .01$. Because gender was also entered as a predictor in Step 3, its confounding role can be excluded.

As can be seen in Panel B of Table 2, no significant effects emerged in the recognition group in Step 1-2, and this was the case also in Step 3, after entering gender and the dummy variables representing list-difficulty (trait anxiety: $B = -0.011$, $SE_B = 0.030$, $\beta = -.11$, $p = .71$;

trait worry: $B = 0.009$, $SE_B = 0.020$, $\beta = .13$, $p = .68$; model fit: $F(6, 43) = 0.98$, $p = .45$). Thus, the link between trait worry and good memory performance was specific to the free recall task, and was not present in the case of the recognition task.

(Table 2 about here)

Study 2

In Study 2, we aimed to replicate the results of Study 1 and to control for potential confounders. We again contrasted free recall and recognition, as analogues of self-cued and environmentally-cued retrieval. This time, however, pictorial stimuli, faces of well-known actors and actresses, were presented to the participants. Besides, we controlled the level of perfectionism and state anxiety.

Method

Participants. One-hundred and fourteen participants, 54 female, $M_{\text{age}} = 21.40$ years, $SD = 2.26$, range = 18-34, were recruited from the Budapest University of Technology and Economics. They participated in exchange for partial credit in introductory psychology courses.

Material. In addition to the measures used in Study 1, we used the State subscale of the State Trait Anxiety Questionnaire, Form X (STAI-S, Spielberger et al., 1970, Hungarian version: Sipos & Sipos, 1983). It consists of 20 items describing physiological and psychological signs of anxiety. The participants have to rate on a four point scale ranging from 1 (*not at all*) to 4 (*extremely*), to which extent they experience these signs at the moment.

To account for motivational factors, we measured time on task for both memory tasks. Besides, participants also filled out seven items of the Frost Multidimensional Perfectionism Scale (FMPS; Frost et al., 1990), constituting the Personal Standards subscale (FMPS-PS).

The items are scored on a five point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) and were translated to Hungarian for the purposes of the present study.

The memory tasks were conducted using Presentation® software (Neurobehavioral Systems, CA, USA). Stimuli were selected from 74 pictures taken from free internet databases, all depicting faces of well-known, famous actors, actresses or musicians.

Design. Recall type was varied between subjects: 56 participants, 24 female, M_{age} = 21.55 years, *SD* = 2.27, range = 19–34, completed the free recall task (recall group), whereas 58 participants, 27 female, M_{age} = 21.22 years, *SD* = 2.23, range = 18–30, completed the recognition task (recognition group). In the recall group, FMPS-PS and STAI-S data were missing for nine participants.

Procedure. During a stimulus selection procedure preceding the learning phase, participants were presented with the 74 faces sequentially, and were asked to provide the name belonging to the given face. The procedure was stopped after the participant identified 28 faces. If less than 28 famous faces were successfully named, a second selection round was initiated in which, if the participant requested, the experimenter helped by providing the first name of the famous person. If unable to identify 28 pictures in the two selection rounds, participants (22 altogether) were excluded from the experiment.

In the subsequent learning phase, 14 of the selected 28 faces were selected at random and presented in a random order. Otherwise, the learning and delay phase was identical to Study 1. In the free recall task, participants had to recall the names belonging to the faces presented and type the recalled name via a keyboard. In the recognition task, all 28 faces were presented in a random order and participants were asked to indicate with a key-press whether they recognized the faces presented during the learning phase. The questionnaires were filled out between the selection and the learning phases.

Data analysis. All analyses were identical to those conducted in Study 1, with two exceptions. First, the distribution of recall percentage was not skewed, thus no log transformation was necessary. Second, a different set of confounders was entered in Step 3: besides gender, we also entered FMPS-PS, STAI-S, and time spent on the final memory task. Due to their superior prior knowledge, we expected superior memory performance for participants succeeding in the first round of the selection phase. Thus, to avoid clustering of observations, similar to Study 1, we also entered a dummy variable representing in which selection round the participant identified the 28 faces.

Results and Discussion

Descriptive statistics related to PSWQ, STAI-T and memory performance are presented in Table 1. The mean total score, computed for the whole sample was 33.83 (SD = 13.30) for STAI-S and 16.94 (SD = 4.78) for FMPS-PS. Trait worry and trait anxiety were correlated in both groups (recall group: $r = .73$, $p < .001$; recognition group: $r = .80$, $p < .001$). The result of the first two steps of the regression analyses are shown in Table 3. Contrary to Hypothesis 1, trait worry was not associated with higher recall percentage (Step 1b: $\beta = .08$, $p = .55$). In line with Hypothesis 2, however, we observed a suppressor situation: controlling their shared variance significantly altered the effect of both trait worry and trait anxiety, and as a consequence, they became oppositely linked to recall percentage (trait anxiety - Step 1a: $\beta = -.17$, Step 2: $\beta = -.50$, standardized indirect effect through trait anxiety: .32, 95% CI[-.03, .65]); trait worry - Step 1b: β=.08, Step 2: β= .44, standardized indirect effect through trait anxiety -.36, 95% CI[-.76, -.01]). Although in the case of trait anxiety, the indirect effect was only marginally significant, the opposite partial effects of trait anxiety and trait worry remained significant in Step 3, after entering several potential confounders (trait anxiety: B = -0.010, SE_B = 0.005, $\beta = -.47$, $p = .04$; trait worry: B = 0.009, SE_B = 0.003, $\beta = .58$, $p = .01$; model fit: $F(7, 39) = 3.55$, $p = .005$), indicating that the demonstrated pattern is independent of these factors. Thus, in contrast to Study 1, we could demonstrate the link between trait worry and free recall performance only after controlling for trait anxiety. In the recognition group, neither trait worry nor trait anxiety predicted memory performance in Step 1-2 (see Panel B of Table 3), and the same was true for Step 3 (trait anxiety: $B = -0.004$, $SE_B = 0.016$, $\beta = -.08$, $p = .78$; trait worry: $B = 0.05$, $SE_B = 0.011$, $\beta = .08$, $p = .39$; model fit: $F(7, 50) = 4.3$, $p < .001$).

(Table 3 about here)

Study 3

The first two studies used a between-study design, thus differences between the groups could have caused the different effects of the anxiety measures on self-cued and on environmentally-cued retrieval. Moreover we used in both studies recognition task to assess environmentally-cued retrieval. Recognition, however, is a less demanding task, than free recall, thus ceiling effects might have also contributed to the lack of effect seen in environmentally-cued retrieval. Thus, in Study 3, we used a within-subject design and a different, more demanding task for environmentally-cued retrieval: a paired-associates learning paradigm.

Method

Participants. Forty-seven undergraduate students of the Pázmány Péter Catholic University, Hungary, volunteered, 30 female, $M_{age} = 22.09$, $SD = 2.00$, range = 19-28.

Material. To measure trait worry and trait anxiety, the instruments used in Study 1 were applied. Based on a Hungarian word frequency norm (Kónya & Pintér, 1985), two sets of 16 weakly associated word pairs were constructed, all words being moderately frequent nouns and all pairs containing two words from different categories.

Design. In Study 1-2 we used a between-subjects design, thus group-differences could have contributed to the differences observed between self-cued and environmentally-cued retrieval. Thus, in Study 3, task type (free vs. cued recall) was varied within-subject, with all participants taking part in both tasks. One of the word-pair lists was used in the cued recall task, whereas the target-words from the other word-pair list were used in the free recall task. Pairing of the word-pair lists with the memory task was counterbalanced, as was the order of the two memory tasks.

Procedure. The memory tasks were conducted successively in one session. To reduce proactive interference, participants filled out the PSWQ and the STAI-T between the two memory tasks. In the learning phase, each word-pair in the cued recall task and each word in the free recall task was shown for four seconds on a computer screen with no inter item interval. The delay period lasted five minutes. Then, in the free recall task, participants had to write down the previously presented words on a sheet of paper, whereas in the cued recall task, the cue words were presented successively and participants had to write down the target word. The to-be-learned material in the learning phase, and the cue words in the test-phase were presented in the same order for each participant.

Data analysis. All analyses were identical to the ones performed in Study 2, except for the set of confounders entered in Step 3 of the hierarchical linear regression analyses: beside gender and time on task, we also entered a dummy variable representing task order, because this might have affected recall levels – causing the clustering of observations.

Results and Discussion

Descriptive statistics are presented in Table 1. Trait worry and trait anxiety were significantly correlated ($r = .62$, $p < .001$). Recall percentage was higher in the cued than in the free recall task, $t(46) = 3.72$, $p < .001$.

The results of the first two steps of the hierarchical regression analyses are shown in Table 4. Contrary to Hypothesis 1, there was only a nonsignificant tendency relating trait worry to better free recall performance (Step 1b: $\beta = .25$, $p = .09$), and in line with Hypothesis

2, controlling their shared variance significantly altered the effect of both trait anxiety and trait worry on recall percentage in the free recall task (trait anxiety - Step 1a: β = -.18, Step 2: β = -.54, standardized indirect effect through trait worry .36, 95% CI[.15, .68]; trait worry - Step 1b: β = .25, Step 2: β = .59, standardized indirect effect through trait anxiety -.33, 95% CI[-.58, -.17]). The pattern of results remained the same also in Step 3, after controlling the effect of gender, time on task and task order (trait anxiety: B = -0.012, SE_B = 0.004, β = -.50, p = .004; trait worry: B = 0.009, SE_B = 0.003, β = .52, p = .003; model fit: $F(5, 41) = 5.02$, p = .001). No similar effects were found for the cued recall performance, either in Step 1-2 (see Panel B of Table 4) or in Step 3 (trait anxiety: B = -0.005, SE_B = 0.005, β = -.19, p = .37; trait worry: B = 0.003, SE_B = 0.004, β = .15, p = .49; model fit: $F(5, 41) = 0.21$, p = .95).

(Table 4 about here)

Study 4

In the first three studies, we assessed memory performance by only one test, which might have led to low reliability of our memory measures. Thus, to increase the reliability of measurement and the validity of our findings, in Study 4, we assessed memory performance multiple times.

Method

Participants. Fifty-two undergraduate students were paid for their participation, 38 female, M_{age} = 22.08, SD =1.88, range = 19-28.

Material. We created six word lists of 14 words by using the words from Study 1 (we made only minor changes to the earlier lists). We created three list of 18 words, which were used as new words in the recognition tasks. The new words were matched in length and frequency to the to-be-remembered words. The new words were selected based on the Hungarian word frequency norm (Kónya & Pintér, 1985). Trait worry and trait anxiety was measured similarly to earlier studies.

Design. Task type (free recall vs. recognition) was varied within subject, with two experimental sessions: in one of the sessions, participants completed three free recall, whereas in the other session, they completed three recognition tasks successively. The pairing of task type (free recall or recognition) with session (1^{st} or 2^{nd}) was counterbalanced. The assignment of the word lists to the specific task followed a pseudorandom order using four different sequences. In these sequences, the lists were assigned to different task (free recall or recognition), to different session (1^{st} or 2^{nd}) and to different positions in the specific session (1^{st}, 2^{nd}, or 3^{rd}).

Procedure. The stimulus presentation software Presentation® was used (Neurobehavioral Systems, CA, USA). For both task type, the words were presented in random order. Then a delay of 5 minutes followed, filled in with mathematical problem solving. Finally, participants conducted either a free recall or a recognition task, which were similar to that used in Study 2. Anxiety measures were administered at both sessions. To reduce proactive interference, participants filled out the anxiety measures in between the memory tasks. At the end of each session, we used a Likert scale, to assess participants' subjective assessment of retrieval effort during retrieval and the interference their experienced during the session. After the second session, participants were debriefed.

Data analysis.

Similarly to previous studies, hierarchical linear regression analyses were conducted. Recall rates and sensitivity values were averaged across the three tasks, and were used as dependent variables. PSWQ/ STAI-T scores from the two sessions were also averaged, as were the subjective estimates of effort/interference. The regression analyses were identical to the ones performed in Study 2, except for the set of confounders entered in Step 3 of the hierarchical linear regression analyses: beside gender and time on task, we entered three dummy variables representing which pseudorandom sequence was used for the participant and also the subjective estimate of the participants regarding retrieval effort and interference, respectively. If assumptions were met, Pearson's, otherwise Spearman's correlation coefficient was used to compute test-retest correlations of memory and anxiety measures.

Results and Discussion. Descriptive statistics are presented in Table 1. Test-retest reliability of the anxiety measures were high (PSWQ: $r = 0.93$, $p < .05$ STAI: $rho = 0.76$, $p < .05$), whereas the correlations between memory performance between the three memory task was modest (recall percentage: $rho_{1st\text{-}2nd} = 0.48$, $p < .001$, $rho_{1st\text{-}3rd} = 0.51$, $p < .001$, $rho_{2nd\text{-}3rd} = 0.38$, $p < .001$; recognition sensitivity: $rho_{1st\text{-}2nd} = 0.47$, $p < .001$, $r_{1st\text{-}3rd} = 0.22$, $p = 10.$, $rho_{2nd\text{-}3rd} = 0.29$, $p < .05$).

As can be seen in Table 5, contrary to Hypothesis 1, trait worry was not related to free recall performance in Step 1 (Step 1b: $\beta = .03$, $p = .86$). In line with Hypothesis 2, however, after controlling their shared variance, both the effect of trait anxiety and trait worry increases significantly (trait anxiety - Step 1a: $\beta = -.15$, Step 2: $\beta = -.54$, standardized indirect effect through trait worry: .39, 95% CI[.04, .70]; trait worry - Step 1b: $\beta = .03$, Step 2: $\beta = .47$, standardized indirect effect through trait anxiety: -.45, 95% CI[-.75, -.16]). Similar to Study 1, the fit of Step 2 model was insufficient, $F(2, 49) = 2.52$, $p = .09$, but the pattern of results remained unchanged in Step 3, after entering several confounding variables increased model fit (trait anxiety: $B = -0.009$, $SE_B = 0.003$, $\beta = -.55$, $p = .014$; trait worry: $B = 0.005$, $SE_B = 0.002$, $\beta = .50$, $p = .03$; model fit: $F(8, 43) = 3.26$, $p = .001$).

Finally, no similar effects were found for recognition sensitivity, either in Step 1-2 (see Panel B of Table 5) or in Step 3 (trait anxiety: $B = -0.005$, $SE_B = 0.005$, $\beta = -.19$, $p = .37$; trait worry: $B = 0.003$, $SE_B = 0.004$, $\beta = .15$, $p = .49$; model fit: $F(5, 41) = 0.21$, $p = .95$).

(Table 5 about here)

Additional Analyses

Comparing partial and indirect effects in self- versus environmentally-cued recall. In all four studies, we observed significant effects for self-cued, but not for environmentally-cued retrieval. As each study used a relatively small sample, however, the demonstrated effects might be present in the environmentally-cued condition too, but undetected due to low statistical power.

To increase statistical power, we used meta-analytical methods for combining the results of our studies. We applied the Hedges-Vevea random-effect model (Hedges & Vevea, 1998), and used the observed effect size estimates from each study (standardized indirect effect estimates for the suppression effect, and regression coefficients for the partial effects) to estimate the population effect determining these observed effects. Table 6 contains the population estimates, significance tests and 95% CIs.

This analysis revealed significant partial effects of the anxiety measures for both the self-cued and environmentally-cued retrieval, respectively. Crucially, the partial effects related to both trait worry and trait anxiety were higher in the former case, as the 95% CIs were nonoverlapping. Furthermore, the indirect effects of the anxiety measures were significant in the case of self-cued retrieval, whereas there was only a nonsignificant tendency for the suppressor effects in environmentally-cued retrieval. Despite the large nominal difference between indirect effects related to self and environmentally cued retrieval, CIs of the estimates overlap, so no significant differences in the magnitude of suppression could be demonstrated.

(Table 6 about here)

Analysis of Temporal Contiguity. Free recall requires cognitive control for the generation of retrieval cues, and one of the crucial processes involved might be the reinstatement of temporal context (Sederberg et al., 2008). Thus, if the demonstrated link between trait worry and free recall is due to the involvement of cognitive control in cue-generation, as hypothesized, then trait worry should be related not only to overall recall level, but also to individual differences in temporal context reinstatement.

Thus, in a post-hoc analysis, we examined whether trait worry is related to individual differences in the tendency to recall items from neighbouring study positions successively. To represent these individual differences in a single variable, Sederberg, Miller, Howard, and Kahana (2010) computed a nonparametric, rank-based summary measure, called temporal factor, whereas Healey, Crutchley, and Kahana (2014) relied on factor analytic procedures. Both methods rely on data from experiments with several free recall trials per participant using a short or even no delay. Our design characteristics differed from the above studies, which might be suboptimal for these analyses, resulting in biased estimates.

Because of this, we used an alternative approach: First, we calculated the absolute lag for each recall transition, that is the absolute value of the difference between study-position of the previously and the currently recalled word. Then, we computed the proportion of the retrieved items which was retrieved from a neighbouring study position of the previously recalled item *(temporally similar item recall percentage, TSI%)*: we counted the number of recalled items, for which the absolute lag was not higher than a maximum lag value (denoted with *k*), and then divided this count by the number of retrieved items. Because we did not want to decide arbitrarily what counts as a recall from a neighbouring position, we gradually changed the value of maximum lag *k* from one to nine, resulting in nine TSI% values, with a more and more relaxed definition of temporal similarity ($TSI\%_{k=1}$, $TSI\%_{k=2}$, ..., $TSI\%_{k=9}$).

In a similar way, we computed the proportion of the original memory set which were recalled *not* from neighbouring study positions of the previously recalled item (*temporally nonsimilar item recall percentage, TNI%*): We first counted the number of temporally similar items, for which the lag was not smaller than a minimum lag value (denoted with l). Then this count was divided by the number of studied items. Again, by increasing the value of the minimum lag *l* from two to ten[1], we calculated nine TNI% values, with more and more constrained definition of temporal nonsimilarity (TNI%$_{l=2}$, TNI%$_{l=3}$, ..., TNI%$_{l=10}$). For the calculation of both TSI% and TNI% values, respectively, we excluded the first recalled item and items recalled after intrusion errors, because for these items, temporal lag could not be defined. The values of the different TSI% and TNI% indices are presented in Figure 1A.

Because the opposite partial effects of trait worry and trait anxiety were demonstrated in all four studies, and study-specific differences were of no importance here, we pooled together the samples from Study 1-4. Data from seven participants, with no consecutive correct recalls, were excluded, thus the sample for this analysis was N=196 (overall recall level: M =.48, SD = 0.22).

Then, we performed 18 linear regression analyses with the different TSI% and TNI% values, respectively, as criterion variables. The predictors were trait anxiety, trait worry and three dummy-variables controlling for study-specific effects in recall level. Because of the high sample size and significant study-specific differences, model fit was appropriate in all cases (all Fs > 2.12, ps < .05), except for TSI%$_{k=7}$, TSI%$_{k=8}$, TSI%$_{k=9}$, where the F test failed to reach significance.

Figure 1B shows the standardized regression coefficients of trait worry and trait anxiety, respectively, predicting TSI%, as a function of maximum lag *k*. The effect of trait worry was significant, when the maximum lag used for TSI% was higher than two, whereas the opposite effect of trait anxiety was significant for TSI%$_{k=4}$,TSI%$_{k=6}$, and TSI%$_{k=7}$. In contrast, we found no effect for either trait worry or trait anxiety in predicting TNI% values, regardless of the minimum lag used (see Figure 1C). Thus, the effects related to the anxiety measures are only present, if the criterion variable represent the retrieval of temporally similar items. This pattern of results suggests that the opposite partial effects of trait worry and trait anxiety demonstrated in Study 1-4 are mediated through the recall of temporally similar items.

(Figure 1 about here)

General Discussion

In four studies, we demonstrated a positive association between trait worry and performance in episodic memory tasks requiring self-cued retrieval. In three of these studies, this link was only revealed after controlling the level of trait anxiety. Consequently, we identified a strong interplay between trait anxiety and trait worry: controlling their shared variance, trait worry exerted a consistent positive effect whereas trait anxiety exerted a consistent negative effect on self-cued memory performance (although in Study 1 the partial effect of trait anxiety was not significant). We also ruled out the potential confounding role of gender, state anxiety, high motivation and perfectionism.

In line with our hypotheses, these effects were not present in any of our four studies for tasks requiring environmentally-cued retrieval. Interestingly, and in contrast with our predictions, a follow-up meta-analysis combining the results of our studies showed that there is a small, but significant aggregate partial effect of the anxiety measures even in the case of environmentally-cued retrieval. This might be explained by the fact that there are no process pure memory tasks (Jacoby, 1991), and different cognitive processes can contribute to performance in any memory task. Indeed, although control processes are essential to self-cued retrieval, they might also operate in parallel with the more automatic, cue-driven processes of environmentally cued retrieval. For instance, during a recognition task, participants may rely on control processes to retrieve contextual details to inform their decision on whether they have seen the presented target or not. Because cognitive control requirement is more pronounced for self-cued retrieval (where these control processes play a decisive role), than for environmentally-cued retrieval (where these control processes are not essential), the significantly stronger partial effect trait worry in self-cued versus environmentally-cued retrieval, revealed by our meta-analysis, also supports the claim that trait worry is associated with cognitive control processes underlying episodic retrieval. This interpretation is further bolstered by our post-hoc analyses showing that our findings were related to the contiguity effect, a marker of the cue-generation process during free recall (Sederberg et al., 2008).

In the following, we turn to two crucial questions regarding the interpretation of our results: (1) theoretical meaning of the demonstrated partial effects, and (2) processes differentiating self-cued vs. environmentally-cued retrieval.

The Partial Effects of Trait Anxiety and Trait Worry

In all four studies, we found consistent opposite partial effects of trait worry and trait anxiety on free recall performance. Importantly, however, these partial effects do not represent the impact of the original constructs, as the common part of the predictors' variance is removed in multiple regression analysis (see e.g. Lynam, 2006). In our case, the observed correlations of trait worry and trait anxiety were about .7, and this implies that about half of the constructs' variance is shared, and thus only the remaining 50% of the variance is responsible for the demonstrated partial effects. Although one could argue that this independent variance simply reflects measurement error, we suggest that the independent parts of trait worry and trait anxiety are theoretically meaningful for three reasons: (1) the scales have high internal consistency indicating low measurement error, (2) the partial effects are related to self-cued and environmentally-cued retrieval in a meaningful manner, and (3) previous findings have already indicated partial independence of the constructs (Davey et al., 1992; Pajkossy et al., 2009; Siddique et al.,2006). Nevertheless, these partial effects do not represent the original constructs anymore, thus, following the advice of Lynam et al. (2006), we propose an explanation about what they theoretically stand for.

The independent part of trait worry, after controlling trait anxiety highlights the fact that individuals with similar levels of trait anxiety might differ somewhat in their tendency to worry. We suggest that the degree to which anxiety manifests itself in a tendency to engage in worrying, is determined by the same cognitive control processes which contribute to free recall performance, explaining the positive partial link between trait worry and free recall. In a similar vein, the partial effect of trait anxiety, after controlling trait worry, represents to which degree worry, a threat-related mental problem-solving activity, is associated with other signs and symptoms of anxiety. One of these signs is reduced attentional control disrupting the retrieval process, thus explaining the partial negative effect between trait anxiety and free recall performance.

Alternatively, taking into account the comorbidity of anxiety and depression (e.g. Pollack, 2005), and the suggested contamination of the STAI scale with depressive symptomatology (Bados, Gómez-Benito, & Balaguer, 2010; Bieling, Antony, & Swinson, 1998), partialling out the shared variance of PSWQ and STAI might remove adverse effects of depression. There is data suggesting that depression decreases memory performance especially if strategic processing is required (Hertel, 2001), thus the negative partial effect of trait anxiety on memory performance requiring strategic retrieval might also reflect this effect, or the combination of negative effects related to both anxiety and depression.

The Self-Cued vs. Environmentally-Cued Distinction—What Does It Represent?

Originally, we contrasted self-cued and environmentally-cued retrieval because self-cued, but not environmentally-cued, retrieval requires mental effort and attentional resources to initiate a cue-generation process (Conway & Pleydell-Pearce, 2000; Moscovitch, 1994; Petrides, 1996). Just as self-cued retrieval, worrying might also require effortful processing to engage in mental-problem solving attempts (Borkovec et al., 1983), to focus on abstract verbal worries (Price & Mohlman, 2007) or to engage in analytic, verbal processing associated with systematic processing (Dash et al., 2013). Thus the partial effect of trait worry on self-cued retrieval observed in our study might be linked to the control of processing resources, capturing the ability to effectively recruit effortful, strategic retrieval processes during cue-generation.

Alternatively, self-cued, but not environmentally-cued, retrieval relies heavily on the formation of semantic associations between items at encoding (e.g. words from the same category are retrieved subsequently) and on the strategic search of semantic memory at retrieval (e.g. search for items of a semantic category and assess its familiarity) (see e.g. Long et al, 2010). The tendency of worrying has been associated with both verbal predominance (Borkovec & Sibrava, 2006) and the analytic, verbal mode of systematic information processing (Dash et al., 2013), thus the link between trait worry and free recall performance might be mediated by the ease of verbal-conceptual processing enhancing organizational strategies at encoding and strategic semantic search at retrieval. Common neural pathway might be the language-related brain network of the left prefrontal cortex, associated with worry and anxious apprehension (Heller, Nitschke, Etienne, & Miller, 1997, Engels et al, 2007), with encoding operations and strategic retrieval in episodic memory tasks (e.g. Nolde, 1998, Long, Öztekin, Badre, & 2010) and also with systematic information processing (Dash et al, 2013). A recent study directly supports this interpretation: after controlling the level of negative affectivity and test anxiety, trait worry was found to be positively associated with verbal, but not with nonverbal intelligence (Penney, Miedema, & Mazmanian, 2015).

Finally, self-cued, but not environmentally-cued, retrieval depends crucially on contextual cues (Kahana, 1996, Sederberg et al, 2008), thus the link between trait worry and free recall performance might be mediated by the effective binding of items to context at encoding and by the effective reinstatement of temporal context at retrieval. Binding and recollection of contextual details underlie not only the re-experiencing of past events (e.g.

Howard & Eichenbaum, 2012), but also imagining future events (Schacter, Addis, & Buckner, 2007) and projecting the self into the past and the future (Buckner & Carroll, 2007). These processes are evidently related to the suggestions relating worry to planning (Barlow, 2002) and future-oriented mental problem solving activity (Borkovec et al, 1983), offering the possibility that the common processes underlying the ability to re-experience the past and imagine the future might underlie the link between trait worry and free recall performance. Because medial-temporal lobe structures and particularly the hippocampus are suggested to be involved in these processes (Howard & Eichenbaum, 2012; Schacter et al, 2007), this interpretation might also be relevant with respect to claims about the involvement of the hippocampus in both anxiety and memory (Gray & McNaughton, 2000, Davidson & Jarrard, 2004; Bannerman et al., 2014).

The current study cannot provide decisive evidence in favour of any of the theoretical alternatives delineated above. Thus, further research is warranted to specify the cognitive control processes responsible for the demonstrated positive association between trait worry and self-cued retrieval.

Finally, some limitations of our research must be addressed. First, our participants were undergraduate students, thus our results cannot be generalized to samples with high levels of pathological worry or anxiety. Second, we assessed the level of pathological worrying as measured by the PSWQ, thus further research should clarify whether the same pattern of results could be observed using measures of nonpathological worrying (e.g. the Worry Domains Questionnaire; Tallis, Eysenck, & Matthews, 1992). Third, our studies were correlational in nature, and therefore provide only indirect support for our hypothesis about common underlying cognitive processes contributing to both trait worry and strategic retrieval.

Notwithstanding these limitations, we demonstrated that the unique variance of trait worry, independent of trait anxiety predicts better self-cued, and to a lesser degree, also better environmentally-cued retrieval. This association seems to arise due to common cognitive processes underlying trait worry and memory retrieval. Future studies, bridging gaps between memory and anxiety research, are required to identify these common processes and to describe the underlying causal relations.

Footnotes

[1] Because a minimum lag value of one would imply that all words are counted, the value of l was varied between two and ten.

References

American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders. (5th ed).* American Psychiatric Association, Arlington, VA.

Baddeley, A.D. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology, 49,* 5–28. doi:10.1080/713755608

Bados, A., Gómez-Benito, J., & Balaguer, G. (2010). The state-trait anxiety inventory, trait version: does it really measure anxiety?. *Journal of Personality Assessment, 92*(6), 560-567.

Bannerman, D. M., Sprengel, D. M., Sanderson, D. J., McHugh, S. B., Rawlins J. N. P., Monyer, H., Seeburg, P. H. (2014). Hippocampal synaptic plasticity, spatial memory and anxiety. *Nature Reviews Neuroscience, 15*, 181–192. doi: 10.1038/nrn3677

Barlow, D.H. (2002). *Anxiety and its Disorders: The Nature and Treatment of Anxiety and Panic* (2nd ed.). New York: Guilford.

Bieling, P. J., Antony, M. M., & Swinson, R. P. (1998). The State-Trait Anxiety Inventory, trait version: Structure and content re-examined. *Behaviour Research and Therapy, 36*, 777–788.

Borkovec, T. D., Robinson, E., Pruzinsky, T., & DePree, J. A. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behaviour Research and Therapy, 21*(1), 9–16. doi:10.1016/0005-7967(83)90121-3

Buckner, R. L., & Carroll, D. C. (2007). Self-projection and the brain. *Trends in Cognitive Sciences, 11*(2), 49-57. doi:10.1016/j.tics.2006.11.004

Brand, M., & Markowitsch, H. J. (2008). The role of prefrontal cortex in episodic memory. In E. Dere, A. Easton, L. Nadel, J. P. Huston (Eds.), *The Handbook of Episodic Memory.* (pp. 317-342). Amsterdam, Netherlands: Elsevier.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied Multiple Correlation/ Regression Analysis for the Social Sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Conger, A. J. (1974). A revised definition of suppressor variables: A guide to their identification and interpretation. *Educational and Psychological Measurement, 34*, 35-46. doi:10.1177/001316447403400105

Conway M. A. (2009). Episodic memories. *Neuropsychologia, 47*, 2305–2313. doi:10.1016/j.neuropsychologia.2009.02.003

Conway, M. A., & Pleydell-Pearce, C. W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review, 107*(2)*,* 261-288. doi:10.1037/0033-295X.107.2.261

Coplan, J. D., Hodulik, S., Mathew, S. J., Mao, X., Hof, P. R., Gorman, J. M., & Shungu, D. C. (2011): The relationship between intelligence and anxiety: an association with subcortical white matter metabolism. *Frontiers in Evolutionary Neuroscience*, *3*(8). doi:10.3389/fnevo.2011.00008

Dash, S.R., Meeten, F., Davey, G. C. L. (2013). Systematic information processing style and perseverative worry. *Clinical Psychology Review, 33*(8), 1041–1056. doi:10.1016/j.cpr.2013.08.007

Davey, G. C., Hampton, J., Farrell, J. A., Davidson, S. (1992): Some characteristics of worrying: Evidence for worrying and anxiety as separate constructs. *Personality and Individual Differences, 13*(2) 133-147. doi:10.1016/0191-8869(92)90036-O

Davidson, T. L., & Jarrard, L. E. (2004). The hippocampus and inhibitory learning: a 'Gray area. *Neuroscience & Biobehavioral Reviews. 28*(3), 261-271. doi:10.1016/j.neubiorev.2004.02.001

Engels, A. S., Heller, W., Mohanty, A., Herrington, J. D., Banich, M. T., Webb, A. G., Miller, G. A. (2007). Specificity of regional brain activity in anxiety types during emotion processing. *Psychophysiology, 44*, 352–363. doi:10.1111/j.1469-8986.2007.00518.x

Engle, R.W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11,* 19-23. doi:10.1111/1467-8721.00160

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: the processing efficiency theory. *Cognition & Emotion, 6,* 409–434. doi:10.1080/02699939208409696

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*(2), 336–353. doi:10.1037/1528-3542.7.2.336

Frost, R. O., Marten, P., Lahart, C., & Rosenblate, R. (1990). The dimensions of perfectionism. *Cognitive Therapy and Research, 14*(5), 449-468. doi:10.1007/BF01172967

Healey, M. K., Crutchley, P., & Kahana, M. J. (2014). Individual differences in memory search and their relation to intelligence. *Journal of Experimental Psychology: General, 143*(4), 1553-1569. doi:10.1037/a0036306

Hedges, L. V., & Vevea, J. L. (1998). Fixed- and random-effects models in meta-analysis. *Psychological Methods, 3*(4), 486-504.

Heller, W., Nitschke, J. B., Etienne, M. A., Miller, G. A. (1997). Patterns of regional brain activity differentiate types of anxiety. *Journal of Abnormal Psychology, 106*, 376–385. doi:10.1037/0021-843X.106.3.376

Hertel, P. T. (2000). The cognitive-initiative account of depression-related impairments in memory. In D. L. Medin (Ed.), *The Psychology of Learning and Motivation (*vol. 39, pp. 47-71). New York: Academic Press.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*(5), 513-541.

Gray, J. A. & McNaughton, N. (2000). *The Neuropsychology of Anxiety (2nd ed).* Oxford: University Press.

Hayes S., Hirsch C., Mathews A. (2008). Restriction of working memory capacity during worry. *Journal of Abnormal Psychology, 117,* 712–717. doi:10.1037/a0012908

Herlitz, A., Nilsson, L-G., & Baeckman, L. (1997). Gender differences in episodic memory. *Memory & Cognition, 25,* 801-811. doi:10.3758/BF03211324

Hoehn-Saric, R., Lee, J. S., McLeod, D. R., & Wong, D. F. (2005). The effect of worry on RCBF in non-anxious subjects. *Psychiatry Research: Neuroimaging, 140*, 259–269. doi:10.1016/j.pscychresns.2005.05.013

Holaway, R. M., Rodebaugh, T. L., & Heimberg, R. G. (2006). The epidemiology of worry and generalized anxiety disorder. In: G.C.L. Davey & A. Wells: *Worry and its disorders. Research, theory and treatment.* (pp. 101-121). Chichester: John Wiley & Sons.

Horst, P. (1941). The role of the predictor variables which are independent of the criterion. *Social Science Research Council, 48*, 431-436.

Howard, M. W., & Eichenbaum, H. (2013). The hippocampus, time, and memory across scales. *Journal of Experimental Psychology: General*, *142,* 1211–1230. doi:10.1037/a0033621

Kahana, M. J. (1996). Associative retrieval processes in free recall. *Memory & Cognition,* 24, 103–109. doi:10.3758/BF03197276

Kónya, A., & Pintér, G. (1985). Kategória norma a verbális emlékezet vizsgálatához [Category norms for verbal memory research]. *Hungarian Psychological Review, 2*, 93–111.

Leynes, A. P. (2002). The effect of specific test queries on source-monitoring event-related potentials. *Brain and Cognition, 50*(2), 218–233. doi:10.1016/S0278-2626(02)00505-5

Liddell, H. S. (1949). The role of vigilance in the development of animal neurosis. In P. Hoch & I. Zubin (Eds.), *Anxiety*. New York: Grune & Stratton.

Long, N. M., Öztekin, I., & Badre, D. (2010): Separable prefrontal cortex contributions to free recall. *The Journal of Neuroscience. 30*(33), 10967-10976. doi: 10.1523/JNEUROSCI.2611-10.2010

Lynam, D. R., Hoyle, R. H., & Newman, J. P. (2006). The perils of partialling: Cautionary tales from aggression and psychopathy. *Assessment, 13*(3), 328–341. doi:10.1177/1073191106290562

MacKinnon D. P., Krull J. L., & Lockwood C. M. (2000). Equivalence of the mediation, confounding, and suppression effect. *Prevention Science, 1*(4), 173–181. doi:10.1023/A:1026595011371

Mathew S. J., Mao X., Coplan J. D., Smith E. L., Sackeim H. A., Gorman J. M., & Shungu D. C. (2004). Dorsolateral prefrontal cortical pathology in generalized anxiety disorder: a proton magnetic resonance spectroscopic imaging study. *American Journal of Psychiatry, 161*, 1119–1121. doi:10.1176/appi.ajp.161.6.1119

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the Penn State Worry Questionnaire. *Behaviour Research and Therapy, 28*(6), 487–495. doi:10.1016/0005-7967(90)90135-6

Mohlman J., Price, R. B., Eldreth, D. A., Chazin, D., Glover, D. M., & Kates, W. R. (2009). The relation of worry to prefrontal cortex volume in older adults with and without generalized anxiety disorder. *Psychiatry Research, 173*(2), 121–127. doi:10.1016/j.pscychresns.2008.09.010

Moscovitch, M. (1994). Memory and working-with-memory: a component process model based on modules and central systems. In D. L. Schacter & E. Tulving (Eds.), *Memory systems* (pp. 269-310). Cambridge, MA: MIT Press.

Mueller, E. M., Nguyen, J., Ray, W. J., Borkovec, T. D. (2010). Future-oriented decision making in Generalized Anxiety Disorder is evident across different versions of the Iowa Gambling Task. *Journal of Behavior Therapy and Experimental Psychiatry, 41,* 165–171. doi:10.1016/j.jbtep.2009.12.002

Nolde, S. F., Johnson, M. K., & Raye, C. L. (1998). The role of prefrontal cortex during tests of episodic memory. *Trends in Cognitive Sciences, 2*(10), 399–406. doi:10.1016/S1364-6613(98)01233-9

Pajkossy, P., Dezső, L., Paprika, Z. Z. (2009): The opposite effect of trait and state anxiety on Iowa Gambling Task. *Learning & Perception, 1*(2), 279-295. doi:0.1556/LP.1.2009.2.110

Pajkossy P., Simor, P., Szendi, I., & Racsmány, M. (in press). Hungarian validation of the Penn State Worry Questionnaire (PSWQ) – comparing latent models with one or two method factors using both paper-pencil and online versions of the PSWQ. *European Journal of Psychological Assessment.*

Paulhus, D. L., Robins, R. W., Trzesniewski, K. H., & Tracy, J. L. (2004). Two replicable suppressor situations in personality research. *Multivariate Behavioral Research, 39*(2), 301-326. doi:10.1207/s15327906mbr3902_7

Penney, A. M., Miedema, V. C., Mazmanian, D. (2015). Intelligence and emotional disorders: Is the worrying and ruminating mind a more intelligent mind? *Personality and Individual Differences, 74*, 90-93. doi:10.1016/j.paid.2014.10.005

Perkins, A. M., & Corr, P. J. (2005). Can worriers be winners? The association between worrying and job performance. *Personality and Individual Differences, 38*(1), 25–31. doi:10.1016/j.paid.2004.03.008

Petrides, M. (1996). Specialized systems for the processing of mnemonic information within the primate frontal cortex. *Philosophical Transactions of the Royal Society B, 351,* 1455–1462. doi:10.1098/rstb.1996.0130

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior research methods, 40*(3), 879-891.

Preacher, K. J., & Kelley, K. (2011). Effect size measures for mediation models: quantitative strategies for communicating indirect effects. *Psychological methods, 16*(2), 93.

Price, R. B., & Mohlman, J. (2007). Inhibitory control and symptom severity in late life generalized anxiety disorder. *Behaviour Research and Therapy, 45*(11), 2628-2639. doi:10.1016/j.brat.2007.06.007

Pollack, M. H. (2005). Comorbid anxiety and depression. *The Journal of Clinical Psychiatry, 66*(suppl 8), 22-29.

Purdon, C., & Harrington, J. (2006). Worry in psychopathology. In G.C.L. Davey & A. Wells (Eds.), *Worry and psychological disorders: Theory, assessment and treatment* (pp. 41-51). West Sussex, England: Wiley and Sons.

Rapee, R. M. (1993). The utilisation of working memory by worry. *Behaviour Research and Therapy, 31,* 617–620. doi:10.1016/0005-7967(93)90114-A

Schacter, D L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: the prospective brain. *Nature Reviews Neuroscience 8*, 657-661. doi:10.1038/nrn2213

Sederberg, P. B., Howard, M. W., & Kahana, M. J. (2008). A context-based theory of recency and contiguity in free recall. *Psychological Review, 115*, 893–912. doi: 10.1037/a0013396

Sederberg, P. B., Miller, J. F., Howard, M. W., Kahana, M. J. (2010). The temporal contiguity effect predicts episodic memory performance. *Memory & Cognition,* 38, 689–699. doi: 10.3758/MC.38.6.689

Sibrava, N. J., & Borkovec T. D. (2006). The cognitive avoidance theory of worry. In G. C. L. Davey, A. Wells (Eds.), *Worry and its psychological disorders: Theory, assessment and treatment* (pp. 239-258). West Sussex, England: Wiley and Sons.

Siddique, H. I., LaSalle-Ricci,V. H., Glass, C. R., Arnkoff, D. B., & Díaz, R. J. (2006). Worry, optimism, and expectations as predictors of anxiety and performance in the first year of law school. *Cognitive Therapy and Research, 30*(5), 667-676. doi: 10.1007/s10608-006-9080-3

Sipos, K., & Sipos, M. (1983). The development and validation of the Hungarian form of the STAI. In C.D. Spielberger & R. Diaz-Guerro (Eds.), *Cross-cultural anxiety* (Vol 2., pp. 27-39). Washington, DC: Hemisphere.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science, 283*, 1657–1661. doi:10.1126/science.283.5408.1657

Spielberger, C. D. (1975). Anxiety: State-trait-process. In C. D. Spielberger & I. G. Sarason (Eds.), *Stress and anxiety* (Vol. 1, pp. 115-143). Washington, DC: WHemisphere.

Spielberger, C. D., Gorsuch, R., L., & Lushene, R. E. (1970). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists' Press.

Startup, H. M., & Erickson, T. M. (2006). The Penn State Worry Questionnaire. In: G.C.L. Davey & A. Wells: *Worry and its disorders. Research, theory and treatment.* (pp. 101-121). Chichester: John Wiley & Sons.

Stöber, J., & Otto, K. (2006). Positive conceptions of perfectionism: Approaches, evidence, challenges. *Personality and Social Psychology Review, 10,* 295-319. doi:10.1207/s15327957pspr1004_2

Stöber, J., & Joormann, J. (2001). Worry, procrastination, and perfectionism: Differentiating amount of worry, pathological worry, anxiety, and depression. *Cognitive Therapy and Research, 25*(1), 49-60. doi:10.1023/A:1026474715384

Tallis, F., Eysenck, M. W., & Mathews, A. (1992). A questionnaire for the measurement of nonpathological worry. *Personality and Individual Differences, 13*(2), 161-168. doi:10.1016/0191-8869(92)90038-Q

Tulving, E. (1983). *Elements of episodic memory*. New York, NJ: Oxford University Press.

Tzelgov, J., & Henik, A. (1991). Suppression situations in psychological research: Definitions, implications, and applications. *Psychological Bulletin, 109*(3)*,* 524-536. doi:10.1037/0033-2909.109.3.524

Verkuil, B., Brosschot, J. F., Borkovec, T., & Thayer, J. F. (2009). Acute autonomic effects of experimental worry and cognitive problem solving: Why worry about worry? *International Journal of Clinical and Health Psychology, 9*(3), 439-453.

Zeidner, M. (1998). *Test anxiety: The state of the art*. New York, NJ: Plenum.

Table 1

Descriptive statistics of Study 1-3.

		Study 1	Study 2	Study 3	Study 4
STAI-T	M (SD) α	39.91 (9.27) .89	37.48 (12.39) .88	43.77 (10.16) .89	40.39 (8.50)
PSWQ	M (SD) α	43.13 (13.57) .93	40.39 (13.87) .93	45.06 (13.07) .93	46.29 (13.45)
Free recall - recall percentage	M (SD)	.39 (0.21)	.63 (0.20).	.44 (0.23)	.39 (0.13)
Cued recall - recall percentage	M (SD)			.57 (0.25)	
Recognition- hit rate	M (SD)	.79 (0.18)	.89 (0.10)		.84 (0.13)
Recognition- false alarm rate	M (SD)	.12 (0.12)	.13 (0.15)		.12 (0.10
Recognition – sensitivity	M (SD)	2.26 (0.86)	2.48 (0.78)		2.38 (0.70)

Note. PSWQ: Penn State Worry Questionnaire; STAI-T: Spielberger State-Trait Anxiety Inventory Trait version; α: Cronbach's alpha value indexing internal reliability. For Study 1-2, values related to the questionnaires are computed using the whole sample.

Table 2

Hierarchical Linear Regression Analyses of the Effect of Trait Worry and Trait Anxiety on Recall Percentage and Recognition Sensitivity in Study 1.

Model	Model parameters		Predictor parameters				Indirect effect of the predictor on the criterion [with 95% CI]	
	R^2	*F*-test	Predictor	β	*B*	*SE B*	Unstand.	Stand.
			A) Criterion: Recall Percentage[a]					
Step 1a	.01	0.7	STAI-T	.12	0.003	0.003		
Step 1b	.08	4.1*	PSWQ	.29*	0.005	0.002		
Step 2	.10	2.6+	STAI-T	-.21	-0.005	0.005	.008 [.001, .015]	.33 [.02, .65]
			PSWQ	.45*	0.007	0.003	-..002 [-.008, .002]	-.16 [-.55, .16]
			B) Criterion: Recognition Sensitivity					
Step 1a	.01	0.1	STAI-T	.01	0.001	0.016		
Step 1b	.01	0.4	PSWQ	.09	0.006	0.010		
Step 2	.02	0.5	STAI-T	-.22	-0.022	0.028	.023 [-.025, .006]	.22 [-.24, .61]
			PSWQ	.28	0.018	0.018	-.012 [-.040, .021]	-.18 [-.64, .28]

Note. Data for Step 3 are not presented. PSWQ: Penn State Worry Questionnaire; STAI-T: Spielberger State-Trait Anxiety Inventory Trait version; B: regression coefficient; SE B: standard error of the regression coefficient; β: standardized regression coefficient;

[a] Log transformed values of recall performance were used.

$^+$:p<.1, *:p<.05, **:p<.01;

Table 3

Hierarchical Linear Regression Analyses of the Effect of Trait Worry and Trait Anxiety on Recall Percentage and Recognition Sensitivity in Study 2.

Model	Model parameters		Predictor parameters				Indirect effect of the predictor on the criterion [with 95% CI]	
	R^2	*F*-test	Predictor	β	*B*	*SE B*	Unstand.	Stand.
			A) Criterion: Recall Percentage (free recall)					
Step 1a	.03	1.7	STAI-T	-.17	-0.004	0.003		
Step 1b	.01	0.4	PSWQ	.08	0.001	0.002		
Step 2	.12	3.7*	STAI-T	-.50*	-0.011	0.004	.007 [-.001, .014]	.32 [-.03,-.65]
			PSWQ	.44*	0.007	0.003	-.005 [-.011,-.005]	-.36 [-.76,-.01]
			B) Criterion: Recognition Sensitivity					
Step 1a	.01	0.2	STAI-T	-.05	-0.003	0.007		
Step 1b	.01	0.1	PSWQ	.04	0.002	0.007		
Step 2	.02	0.6	STAI-T	-.24	0.013	0.012	.01 [-.012, .035]	.18 [-.21, .64]
			PSWQ	.23	-0.013	0.012	-.010 [-.037, .010]	-.19 [-.70, .18]

Note. Data for Step 3 are not presented. PSWQ: Penn State Worry Questionnaire; STAI-T: Spielberger State-Trait Anxiety Inventory Trait version; B: regression coefficient; SE B: standard error of the regression coefficient; β: standardized regression coefficient;

$^{+}$:p<.1, *:p<.05, **:p<.01;

Table 4

Hierarchical Linear Regression Analyses Investigating the Effect of Trait Worry and Trait Anxiety on Recall Percentage in the Free and the Cued Recall Tasks in Study 3.

Model	Model parameters		Predictor parameters				Indirect effect of the predictor on the criterion [with 95% CI]	
	R^2	*F*-test	Predictor	β	*B*	*SE B*	Unstand.	Stand.
			A) Criterion: Recall Percentage (free recall)					
Step 1a	.03	1.5	STAI-T	-.18	-0.004	0.003		
Step 1b	.06	3.1+	PSWQ	.25+	0.005	0.003		
Step 2	.25	7.2*	STAI-T	-.54**	-0.012	0.004	.008 [.003, .016]	.36 [.15, .68]
			PSWQ	.59**	0.010	0.003	-.006 [-.011, -.003]	-.33 [-.58, -.17]
			B) Criterion: Recall Percentage (cued recall)					
Step 1a	.01	0.3	STAI-T	-.07	-0.002	0.004		
Step 1b	.01	0.1	PSWQ	.03	0.001	0.003		
Step 2	.02	0.3	STAI-T	-.15	-0.004	0.005	.002 [-.003, .009]	.08 [-.13, .32]
			PSWQ	.13	0.002	0.004	-.002 [-.007, .002]	-.09 [-.37, .10]

Note. Data for Step 3 are not presented. PSWQ: Penn State Worry Questionnaire; STAI-T: Spielberger State-Trait Anxiety Inventory Trait version; B: regression coefficient; SE B: standard error of the regression coefficient; β: standardized regression coefficient; $^{+}$:p<.1, *:p<.05, **:p<.01;

Table 5

Hierarchical Linear Regression Analyses Investigating the Effect of Trait Worry and Trait Anxiety on Recall Percentage in the Free and the Cued Recall Tasks in Study 4.

Model	Model parameters		Predictor parameters				Indirect effect of the predictor on the criterion [with 95% CI]	
	R^2	*F*-test	Predictor	β	*B*	*SE B*	Unstand.	Stand.
			A) Criterion: Recall Percentage (free recall)					
Step 1a	.02	1.2	STAI-T	-.15	-0.002	0.002		
Step 1b	.01	0.1	PSWQ	.03	0.001	0.001		
Step 2	.09	2.5+	STAI-T	-.54*	-0.009	0.004	.006 [.001, .011]	.39 [.04, .70]
			PSWQ	.47+	0.005	0.002	-.005 [-.008,-.002]	-.45 [-.75, -.16]
			B) Criterion: Recognition sensitivity					
Step 1a	.01	0.3	STAI-T	.01	0.001	0.012		
Step 1b	.01	0.1	PSWQ	-.01	-0.001	0.007		
Step 2	.01	0.1	STAI-T	-.02	-0.002	0.021	.001 [-.033, .039]	.02 [-.39, .46]
			PSWQ	.02	0.001	0.013	-.001 [-.022, .021]	.-02 [-.41, .39]

Note. Data for Step 3 are not presented. PSWQ: Penn State Worry Questionnaire; STAI-T: Spielberger State-Trait Anxiety Inventory Trait version; B: regression coefficient; SE B: standard error of the regression coefficient; β: standardized regression coefficient; $^{+}$:p<.1, *:p<.05, **:p<.01;

Table 6.

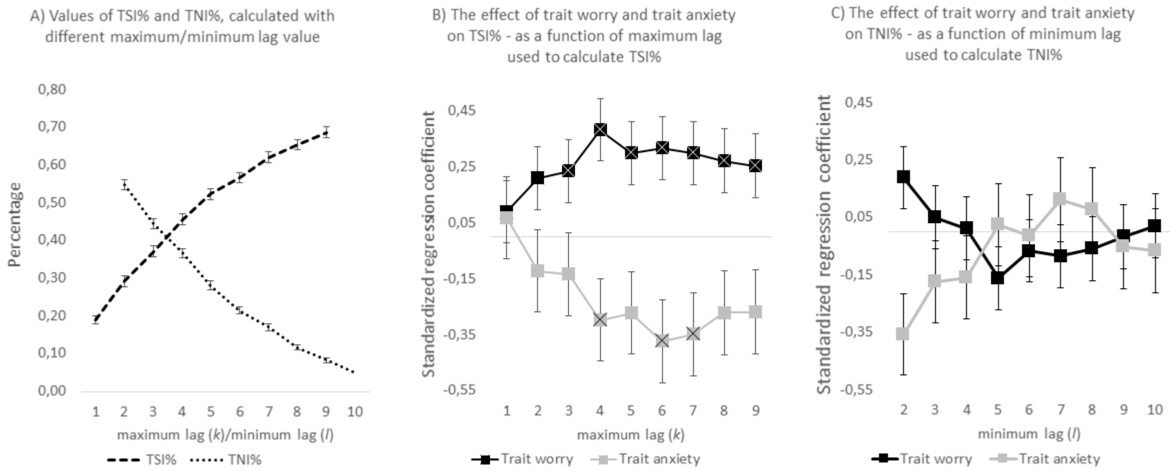
Results of the meta-analysis: Population estimates of partial and indirect effects related to trait worry and trait anxiety.

		Partial effect		Indirect effect	
		Self-cued	Env-cued	Self-cued	Env-cued
PSWQ	Estimate	.49 ***	.16*	-.33***	-.12^{+}
	95% CI	[.37,.59]	[.02, .30]	[-.45, -.20]	[-.26, .02]
STAI	Estimate	-.45***	-.16*	.35***	.13^{+}
	95% CI	[-.59, -.31]	[-.29, -.02]	[.22, .47]	[-.02, .26]

Note. $^{+}$:p<.1, *:p<.05, ***:p<.001; CI: Confidence Interval; Env-cued: Environmentally-cued

Figure 1

The Effect of Trait worry and Trait anxiety on Recall of Temporally Similar and Nonsimilar Items



Note: TSI%: the number of temporally similar items (the absolute lag between the study position of the currently and previously recalled item is not higher than a maximum lag value *k*), divided by the number of retrieved items. TNI%: the number of temporally nonsimilar items (the absolute lag between the study position of the currently and previously recalled item is not smaller than a minimum lag value *l*), divided by the number of retrieved items. (A) Error bars represent the standard error of the mean. (B) Error bars represent the standard error of the regression coefficients. Crossed squares indicate significant regression coefficient. (C) Error bars represent the standard error of the regression coefficients. None of the regression coefficients is significant.