Restriction of Working Memory Capacity during Worry.

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Journal of Abnormal Psychology, *117, 712-717*

For citation: Hayes, S., Hirsch, C.R., & Mathews, A., (2008). Restriction of working memory capacity during worry. Journal of Abnormal Psychology, 117, 712-717. PMID: 18729625

Abstract

We report the first direct assessment of working memory capacity when people engage in worry. High and low worriers performed a random key-press task whilst thinking about a current worry or a positive personally relevant topic. High (but not low) worriers showed more evidence of restricted capacity during worry than when thinking about a positive topic. These findings suggest that high worriers have less residual working memory capacity when worrying than when thinking about other topics, and thus have fewer attentional resources available to redirect their thoughts away from worry.

Keywords: worry; working memory; anxiety; attentional control; random number generation.

Worry is characterised by the repeated experience of apparently uncontrollable thoughts regarding possible future negative events. High worriers are distinguished from low worriers by reported uncontrollability of negative thought intrusions once worrying is initiated (Borkovec, Robinson, Pruzinsky, & DePree, 1983). Chronic excessive and uncontrollable worry is the defining feature of Generalized Anxiety Disorder (GAD; American Psychiatric Association, 1994), a disabling disorder often resulting in severe cognitive, occupational, and social dysfunction (Kessler et al., 1994; Massion, Warshaw, & Keller, 1993). Consequently, it seems important to understand what factors make high levels of worry particularly difficult to control.

Previous evidence has suggested that anxiety is associated with a reduction in available working memory capacity (cf. Eysenck, 1979, 1982; Eysenck & Calvo, 1992). In the model proposed by Baddeley & Hitch (1974; revised by Baddeley, 1986), working memory is a limited cognitive resource that includes temporary stores holding task-related information and a central executive system involved in processing that information when performing tasks. The central executive is similar to the construct of a supervisory attentional system regulating thought and goals (Norman & Shallice, 1986) and to attentional control (Engle & Kane, 2004).

Several studies of anxiety have manipulated working memory when performing a target cognitive task by using a simultaneous secondary task (e.g., Calvo & Ramos, 1989; Darke, 1988; Derakshan & Eysenck, 1998; Eysenck, 1985; MacLeod & Donnellan, 1993; Sorg & Whitney, 1992). All participants showed performance deficits on the target task under high memory load conditions, but these were disproportionately greater for high than low anxious individuals. Eysenck & Calvo (1992) have proposed that this is because worry consumes working memory resources, reducing capacity to perform the target cognitive task. Although these results are *consistent* with the idea that worry leads to restricted working memory capacity, they do not provide any direct evidence that the deficits are in fact attributable to worry, rather than to other individual differences associated with anxiety.

Rapee (1993) assessed the effects on worry of simultaneously performing other tasks: word repetition; random letter generation; and key presses in fixed or random order. Only random letter generation reduced reported worry, although unexpectedly, this did not differ in high or low worriers. It is unclear whether this effect was related to differences in the content of the tasks, or to their demands on central executive attention. More critically, letter generation may interfere with *any* type of thought, rather than just worry. Even if secondary tasks can interfere with worry, this does not address the question of whether worry restricts working memory capacity more than other types of thought.

In the present study we assessed working memory during worry and while thinking about a positive personally-relevant topic in high and low worriers. We employed Baddeley's (1966) dual-task method, whereby performance on a concurrent task (specifically, random generation) was used to measure residual working memory capacity. Generating random sequences requires high levels of attentional monitoring and control (Baddeley, 1986) to overcome the tendency to produce sequences that are well practiced (e.g., ascending or descending series, adjacent key presses). To the extent that limited working memory resources are consumed by other tasks (e.g., worry), the generated output is less random (Baddeley, Emslie, Kolodny, & Duncan, 1998).

We considered two alternate hypotheses about working memory in high worriers. First, worry may reduce randomness more than thinking about a non-worry topic, because worry is attention demanding and takes up more capacity. Predictions for people reporting less frequent worry are less clear, but if worry persists because it is particularly attention demanding and consumes the capacity required to control it, then this should be less true in low worriers and thus have less effect on working memory.

Alternatively, if worrying is relatively automated in high worriers it might consume less capacity, as with expert performance acquired through extended practice (Ericsson & Kintsch, 1995). Over-learned activities such as typing or driving are minimally impaired by secondary tasks (Allport, Antonis, & Reynolds, 1972; Shaffer, 1975). Consequently, worrying could consume less working memory capacity in high worriers, resulting in *greater* randomness whilst worrying, again with no such effect in low-worry controls.

In summary, the current study was designed to assess the effect of worry versus non-worrisome thinking on residual working memory capacity in high and low worriers. All participants performed a random key-press task whilst thinking about either a current worry topic or a positive personally relevant thought topic, in counterbalanced order. Valence of thought content and mood was assessed at critical points throughout the study.

Method

Participants

Thirty-two staff and students of King's College London were selected based on scores on the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990). Molina & Borkovec (1994) found that 55 was one standard deviation above the mean for general samples. Sixteen participants in the low-worrier group scored below 47 on the PSWQ (mean=36.6, *SD*=6.3, range 27-46), and 16 in the high worry group scored above 55 (mean=64.9, *SD*=5.9, range 56-75).

The two worry groups also differed on the Worry Domains Questionnaire Short Form (WDQ-SF; Stober & Joorman, 2001): the low-worry group reported fewer worries on average than the high group (9.2 vs. 20.2; $t(30)=5.76$, $p< .001$). The low-worry group worried less about

Relationships, $t(30)=3.95$, $p< .001$; Lack of Confidence, $t(30)=5.04$, $p< .001$; Aimless Future, $t(30)=3.49$, $p< .005$; and Work, $t(30)=4.50$, $p< .001$; but not Financial worries, $t(30)=0.85$, *ns*.

Each group included 6 males and 10 females, with an average age of 26.7 (*SD*=10.9) not significantly differing between groups, $F(1,31)=0.43$, *ns.* Average years of education was 14.6 (*SD*=2.0), which was not significantly different between groups, $F(1,31)=1.08$, *ns.*

Materials

Worry questionnaires. The PSWQ (Meyer, et al., 1990) consists of 16 statements about worry (e.g., “Once I start worrying, I can’t stop”; “My worries overwhelm me”) rated on a scale from 1 (*not at all typical of me*) to 5 (*very typical of me*), with total scores ranging from 16 to 80. Several studies of the PSWQ have reported high internal consistency, retest reliability, and validity (Davey, 1993). Internal consistency for the current sample (Cronbach’s alpha) was 0.96.

The WDQ-SF (Stober & Joorman, 2001) is a 10-item measure with each rated on a scale of worry frequency from 0 (*not at all*) to 5 (*extremely often*). Total score is the sum of five sub-scales (see above). The WDQ-SF has high internal consistency and a near-perfect correlation with the WDQ long form (Stober & Joorman, 2001). Internal consistency in the current sample was high (Cronbach’s alpha = 0.91).

Experimental apparatus. The experimental task was completed on a Viglen Pentium II computer. The keys corresponding to the letters R, T, Y, U, I, F, G, H, J, C, V, B, N, M on a conventional keyboard were covered by white stickers, forming a block of three rows of five keys. All key-press responses were recorded in Microsoft Office Word (2003), with the monitor switched off. A beeper program (Donaldson, 2004) delivered a ‘beep’ sound at intervals of 3 sec for 5 minutes.

Experimental Task

Random key-pressing task. In the worry thought condition participants were asked to think of a personally relevant current worry topic. The experimenter then asked a series of questions for about 2 minutes following the form 'What would be bad about that?' to identify and prime salient aspects of the topic (Davey & Levy, 1998; Vasey & Borkovec, 1992). Participants were instructed that thinking about this topic would be their *main task* and that every time they heard a beep they should press a random key on the keyboard and then return to the specified topic.

Participants responded with 100 key presses using the 15 item key block for 5 minutes, keeping pace with tones generated by the computer at 3 sec intervals (determined to be optimal in pilot work). The positive thought condition was the same except that participants were required to identify a personally relevant positive topic, and the corresponding questions took the form 'What would be good about that?'(Startup & Davey, 2001).

Randomness data were scored in two ways, considered to be the most sensitive (Baddeley et al., 1998; Towse, 1998). Random Number Generation (*RNG*) is an index on a scale of 0 to 1 based on consecutive key response pairs (Evans, 1978). High RNG scores indicate that pairs of keys were pressed repeatedly rather than equally distributed. Redundancy (*R*; Attneave, 1959; Baddeley, 1966) reflects (on a scale of 0 to 100) the extent to which each key was pressed equally often. For the purposes of analyses, each of the keys were given numerical values, increasing from left to right and top to bottom, from 1 to 15. RNG and R randomness measures were calculated using the software program RGCalc (Towse & Neil, 1998). Higher values indicate less random performance (less working memory capacity) for both.

Mood ratings. Anxiety, depression, and happiness were assessed before and after the worry and positive thought conditions using three visual analogue scales, each 100 mm in length and labelled 'not at all' at one end and 'extremely' at the other. Current mood was indicated with a cross (*x)*, and measured with a millimetre ruler to obtain scores from 0 (*not at all*) to 100 (*extremely*).

Thought ratings. Immediately following each thought condition, participants rated the valence of thoughts and the percentage that were negative, positive, and neutral.

Filler task. To reduce the likelihood of carry-over effects across the two thought conditions, the Speed of Comprehension Test (Version A; Baddeley, Emslie, & Nimmo-Smith, 1992) was administered, consisting of 100 sentences, half of which are “true” (e.g., “Dragonflies have wings”) and half “false” (e.g., “Beer lives in trees”). Participants indicated whether sentences were true or false for 2 minutes. In order to not increase anxiety, instructions were amended to emphasize that speed was not important.

Procedure

Testing was carried out individually in a sound-attenuated room. Participants initially completed a consent form, the PSWQ, WDQ-SF, and mood rating scales. They were allocated to a counterbalanced thought condition order (worry, positive) and received the following instructions: “In this experiment you will be asked to press a series of random keys on a keyboard at the same time as you are thinking about either a worry topic or a more positive topic. You should press one of the white keys on the keyboard every time you hear a beep signal. The order in which you press these keys should be random. What I mean by that is that each key should have an equal chance of being pressed each time. Although it might not happen on a few occasions, over a large number of times each key would be pressed as often as every other key, and in no particular order. Press the keys using the same finger throughout.”

They were then seated in front the computer and given 15 practice trials. When it was clear that all instructions were understood, the first thought topic was identified and the key-pressing task completed. Immediately following this, participants completed the mood rating scales and thought ratings, were administered the filler task for 2 minutes, and by the mood rating scales again. This procedure was then repeated for the other thought condition, with participants required to identify something as personally relevant as the first[1]. Finally, participants were debriefed, thanked for their time, and paid £7.

Results

Self-reported mood

A mixed-model ANOVA was carried out for each of the three mood ratings before and after the worry and positive thought conditions, with one between-subjects factor Group (Low, High), and two repeated measures factors, Condition (Worry, Positive) and Time (Pre-, Post-thought condition). There were main effects of Group for both anxiety, $F(1,28)=10.14$, $p< .005$, $f^2=0.58$; and depression, $F(1,28)=6.81$, $p< .05$, $f^2=0.47$. This reflected higher mean levels of anxiety in the high than the low group (34 vs.14; $t(124)=5.40$, $p< .001$); as well as depression (24 vs.9; $t(124)=4.21$, $p< .001$). There was also an interaction between Condition and Time for anxiety, $F(1,28)=17.43$, $p< .001$, $f^2=0.76$; depression, $F(1,28)=14.31$, $p< .005$, $f^2=0.69$; and happiness, $F(1,28)=21.60$, $p< .001$, $f^2=0.84$. In the worry condition, mean ratings significantly *increased* for anxiety (21 to 28; $t(31)=3.51$, $p< .005$); and depression (14 to 23; $t(31)=3.30$, $p< .005$); and *decreased* for happiness (62 to53; $t(31)=3.43$, $p< .005$). In the positive condition, this pattern was reversed, with a *decrease* in both anxiety (27 to 8; $t(29)=2.74$, $p< .05$); and depression (17 to13; $t(29)=2.19$, $p< .05$); and an *increase* in happiness (61 to 70; $t(29)=3.53$, $p< .005$).

The three-way interaction between Condition, Time, and Group did not approach significance for anxiety, $F(1,28)=0.65$, *ns*; depression, $F(1,28)=1.78$, *ns*; or happiness, *F*(1,28)=0.15, *ns*. Thus although low and high worry participants differed in baseline levels of anxiety and depression, the pattern of change over time was the same; anxiety and depression increased and happiness decreased with worry, and vice-versa in the positive thought condition, regardless of group (see Table 1).

[Table 1 here]

Thought ratings

Reported percentage of thoughts for each valence were examined in a mixed-model ANOVA with one between-subjects factor of Group (Low, High), and two repeated measures, Condition (Worry, Positive), and Content (Negative, Positive, Neutral). The only significant finding was a two-way interaction between Condition and Content, $F(1,30)=17.14$, $p< .001$, $f^2=0.75$. In the worry condition, mean negative thought frequency (58%) exceeded neutral (29%) and positive (13%), $F(2,93)=27.20$, $p< .001$, $f^2=0.95$. Conversely, in the positive condition, positive thought frequency (71%) exceeded neutral (19%) or negative (10%), $F(2,93)=101.80$, $p< .001$, $f^2=1.84$. Bonferroni corrected paired comparisons indicated all comparisons (except negative versus neutral in the positive condition; $t(30)=0.09$, *ns*.) were significant, all $t(30)>1.5$, $p< .05$. Regardless of group, all participants reported more negative thoughts during worry and positive thoughts during the positive condition (see Table 2).

[Table 2 here]

Measures of randomness

RNG and R measures are different scales, so raw scores were standardized for analysis. There were no missing responses for any trials of the key-pressing task for any participants. Total error data (data excluded due to participants making too many random key-press responses) was 3.8%, with no significant differences across groups or thought conditions. An ANOVA on randomness scores, with one between-subjects factor of Group (Low, High) and two repeated measures, Condition (Worry, Positive) and Measure (RNG, R), revealed main effects of Group, $F(1,30)=12.05$, $p< .005$, $f^2=0.63$, with high worriers being less random than the low group (0.42, -0.42), and for Condition, $F(1,30)=7.00$, $p< .05$, $f^2=0.48$, with less random responses while worrying than thinking about a positive topic (0.18, -0.18). Importantly, these effects were qualified by the only significant interaction, between Condition and Group, $F(1,30)=5.72$, $p< .05$, $f^2=0.43$. The high worry group was less random during worry than the positive condition (0.76, 0.08; $t(15)=2.77$, $p< .05$), with no difference in the low group (-0.41, -0.44; $t(15)=0.31$, *ns*.). High worriers had significantly less random responses than low-worriers during both worry, $t(30)=3.48$, $p< .005$, and positive thought, $t(30)=2.51$, $p< .05$. There was no main effect or significant interaction involving randomness Measure, all $F<1$ (see Table 3 for means).

[Table 3 here]

When covariance analyses were conducted on randomness for each condition, with state anxiety as the covariate, the main effect of group remained highly significant for the worry condition, $F(1,31)=9.59$, $p<.005$, $f^2=0.56$, and approached significance for the positive condition, $F(1,31)=4.05$, $p=.054$, $f^2=0.13$. This suggests that randomness differences are unlikely to be due to initial differences in state anxiety. Analyses with depression or happiness as a covariate produced similar results.

Discussion

The pattern of results supported our first hypothesis: worry takes up more working memory capacity in high worriers. High worriers had less residual working memory capacity available when engaging in worry than when thinking about a personally-relevant positive topic. In contrast, residual working memory capacity in low worriers did not differ when they were thinking about a worry versus a positive topic. This effect does not seem attributable to a difference between groups in the proportion of negative and positive thoughts in each thought condition. Content ratings showed that both high and low-worriers reported more negative than positive thoughts in the worry condition and more positive than negative thoughts in the positive condition, so the present findings are unlikely to be due to the worry condition containing more negative than positive thoughts for high worriers only.

Nevertheless, it remains possible that the content of worry in high worriers is objectively more negative than in low-worry controls, and thus commanded more attentional resources. To investigate this possibility, we collected new samples of low and high worriers from the same population, with PSWQ scores matched to those in the present study. For the low worry group, PSWQ means for original versus new samples (SD in parentheses) were 36.56 (6.35) and 34.56 (4.76), $t(30)=1.01$, *ns*; and for the high worry group, 64.94 (5.87) and 66.00 (4.08), $t<1$. A psychology graduate student rated worry topics selected by the new groups as low, medium, or high in negativity, with a sample (25%) re-rated by another assessor to assess reliability (neither assessor was aware of worry group membership). Inter-rater reliability was high (91.7 %), and Chi-square tests of categorisation demonstrated that low and high worry groups did not differ in rated negativity of the worry topics (15 vs. 16 medium; 1 vs. 0 high respectively, $\chi^2(1, N=32)=1.03$, *ns*.). It is impossible to be certain that the same applies to the original sample, but this seems unlikely since both groups were recruited from the same population and were matched for selection criteria. Despite the content of worry topics being equally negative for the two groups, the high worry participants themselves may well perceive the content of their worry topics as being more negative (Vasey & Borkovec, 1992), which could contribute to the depletion of working memory capacity when high worriers worry.

In any event, the present results support the conclusion that high worriers have less residual working memory capacity when worrying than when thinking about a non-worry topic, as speculated in previous studies of anxiety (e.g., Rapee, 1993; MacLeod & Donnellan, 1993). However, as noted earlier, the present study is the first to have directly measured residual working memory capacity during worry and during alternative positive thought.

We have interpreted the present results as showing that worry, relative to positive thought, leads to a reduction in working memory capacity, and specifically in those who are worry-prone. While high worriers were marginally less random than low-worriers when thinking about positive topics, a more robust group difference occurred during worry. It is possible that instruction to focus on positive thoughts was insufficient to prevent some negative intrusions in high worriers and this might explain the group difference under positive thought conditions. Prior research with GAD patients has established that enhanced interference occurs when searching among threatening distractors to find a neutral target, but not when threatening distractors were absent (Mathews, May, Mogg & Eysenck, 1990). The current findings further suggest that high worriers (with GAD) may have a more enduring deficit in attentional control that is enhanced in the presence of threat.

Consistent with previous research (Borkovec, et al., 1983; Vasey & Borkovec, 1992), high worriers reported higher levels of both anxiety and depression than low-worriers. All participants reported greater anxiety and depression in the worry condition than in the positive thought condition, but only high worriers differed in randomness scores across conditions. Furthermore, when mood was partialed out in covariance analyses the critical findings remained significant, supporting previous suggestions that reduction in working memory capacity in high worriers relates to the worry component of anxiety, rather than mood state itself (Rapee, 1993). Nevertheless, given worry correlates highly with trait anxiety, it remains possible that the current findings are due to trait anxiety rather than worry. Future research should investigate this. Notwithstanding this, the current study demonstrates these effects are present in high worriers when they worry, whether this is due to their propensity to worry excessively or be highly anxious.

Another possibility is that the observed group difference is due to equivalent content having different effects on attention in high and low-worriers. Anxiety is characterised by increased attention to threatening cues (Mathews & MacLeod, 1994), and greater difficulty disengaging attention from them (Fox, Russo, Bowles, & Dutton, 2001; Yiend & Mathews, 2001). Thus high worriers may be less able than low-worriers to prevent attentional capture by worry. Attentional control is related to the central executive component of working memory (Engle & Kane, 2004), so that the present findings could be interpreted as being due to worrisome thought content causing differential depletion of attentional control in high worriers. If so, then pre-emption of working memory capacity may make it more difficult to use attentional control to stop worrying (e.g., by thinking about something else or considering more positive outcomes).

Although the present findings were obtained with non-clinical groups, it seems likely that residual working memory capacity is depleted in other emotional disorders, for example during rumination in depression (Watkins & Brown, 2002), as well as during worry in anxiety disorders. If so, the current study may contribute to a better understanding of the mechanisms involved in prolonging perseverative thought in anxiety and depressive disorders, as well as in non-clinical worriers.

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This research was supported by a Medical Research Council (MRC) Grant. The authors would like to thank Eleanor Leigh for collecting data on the degree of negativity of worry topics selected; John Donaldson for writing the Beeper program; and Tom Borkovec for his helpful comments on an earlier draft of this paper.

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Footnotes

(1). During the course of the study we decided it important to consider participants' personal relevance ratings of selected thought topics to ensure there was no difference across thought condition. Following selection of each thought topic a random 50% of participants in each group rated personal relevance on a scale from 0 (not at all) to 10 (highly). For the low group mean rating for worry was 8.38 (*SD* 1.69) and for the positive topic 8.88 (0.99); for the high group the same means were 8.38 (0.74) and 8.50 (1.07). ANOVA revealed no differences due to Group or Thought Condition, nor any significant interaction, all $F(1,16) < 1$.

Table 1

Self-reported mood ratings for the Low and High Worry Groups Pre- and Post- Worry and Positive Thought Conditions (standard deviations in parentheses).

	Anxiety			
	Worry Thought Condition		Positive Thought Condition	
	Pre-	Post-	Pre-	Post-
Low Worry Group	14.40	23.60	12.67	9.47
	(5.34)	(5.59)	(4.69)	(5.21)
High Worry Group	29.40	35.15	42.00	28.53
	(5.34)	(5.59)	(4.69)	(5.21)

	Depression			
	Worry Thought Condition		Positive Thought Condition	
	Pre-	Post-	Pre-	Post-
Low Worry Group	10.27	13.07	8.53	6.40
	(3.85)	(5.10)	(4.43)	(3.60)
High Worry Group	18.40	32.47	24.93	19.40
	(3.85)	(5.10)	(4.43)	(3.60)

Table 1 (cont.)

	Happiness			
	Worry Thought Condition		Positive Thought Condition	
	Pre-	Post-	Pre-	Post-
Low Worry Group	60.00	53.47	58.80	69.07
	(4.10)	(4.58)	(4.72)	(4.56)
High Worry Group	61.67	50.87	62.60	70.07
	(4.10)	(4.58)	(4.72)	(4.56)

Note: 'Pre-' indicates mood ratings before thought condition, 'Post-' indicates mood ratings following thought condition.

Table 2

Percentage of time Low and High Worry Groups reported thinking Negative, Positive, and Neutral Thought Content during Worry and Positive Thought Conditions (standard deviations in parentheses).

	Worry Thought Condition			Positive Thought Condition		
	Negative	Positive	Neutral	Negative	Positive	Neutral
Low Worry Group	52.8%	10.6%	35.9%	6.3%	70.1%	23.6%
	(7.5%)	(4.5%)	(5.6%)	(3.6%)	(5.5%)	(4.7%)
High Worry Group	61.9%	16.2%	21.9%	12.7%	72.4%	13.6%
	(7.5%)	(4.5%)	(5.6%)	(3.6%)	(5.5%)	(4.7%)

Table 3

Randomness measures for the Low and High Worry Groups in Worry and Positive Thought Conditions (standard deviations in parentheses).

	RNG		Redundancy		Standardized Scores	
	Worry	Positive	Worry	Positive	Worry	Positive
Low Worry Group	0.19 (0.05)	0.19 (0.03)	2.42 (1.27)	2.78 (0.97)	-0.41 (0.39)	-0.44 (0.23)
High Worry Group	0.29 (0.12)	0.23 (0.09)	9.40 (7.86)	5.72 (4.77)	0.76 (1.28)	0.08 (0.79)