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The Interplay between Cognition and Worry

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Abstract

An increasing amount of research findings is showing that higher engagement in cognitive tasks alleviates the interference of anxiety and worry on task performance as compared to lower task engagement. Yet, it is still not clear which cognitive functions are mostly contributing to this relieving effect. To add to the current knowledge, the present experimental work investigated the relations between task performance, patterns in pupil dilation and increased difficulty in tasks requiring, among others, cognitive maintenance and updating functions in induced ‘worry’ and ‘no worry’ conditions. In addition, the present experiment explored if visual complexity level of stimuli is modulating these relations. Data analyses of the response speed, proportion of correct answers and pupillary baseline measures revealed statistically significant three-way interactions between the condition (‘worry’, ‘no worry’), visual complexity (low, high), and task (n-back, reference-back). The results showed lower performance measures in the ‘worry’ condition than in the ‘no worry’ condition in an easier n-back task, but this disadvantage was eliminated with increased task difficulty. Results of the reference-back task revealed that increased period of mental object maintenance may be sufficient to shield from disadvantages in the performance efficiency in the ‘worry’ condition. The results also showed that increased visual complexity of stimuli interfered with the task performance more in the ‘worry’ condition than in the ‘no worry’ condition. Pupil dilation data showed higher baseline pupil sizes in the ‘no worry’ condition linked with, among others, higher working memory capacity, as compared to smaller pupil sizes in the ‘worry’ condition.

Keywords: worry, working memory, task engagement, pupil dilation.

Research in the fields of cognition and anxiety indicates that worrisome thoughts and anxious apprehension interact widely with cognitive functioning and is negatively affecting performance in cognitive tasks by impairing use of attentional control mechanisms and cognitive processing resources (e.g., Fernández-Castillo & Caurcel, 2015; Gustavson & Miyake, 2016; Sari, Koster, & Derakshan, 2017). The focus on unfavourable consequences of anxiety and worry on cognition is a leading trend in the field (see Maloney, Sattizahn, & Beilock, 2014; Moran, 2016 for a review). However, an increasing number of studies suggest that increased, as compared to reduced, engagement in certain cognitive tasks can lower anxiety and shield task performance from detrimental effects of worry and anxiety (e.g. Clarke & Johnstone, 2013; Patel et al., 2015; Vytal, Cornwell, Arkin, & Grillon, 2012; Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013).

The present experimental work is aiming to contribute to the current knowledge regarding the relations between cognition and worry by further investigating how specific cognitive maintenance and updating functions interact with worry and if increased engagement in the tasks requiring these functions is helping to alleviate possible negative effects of worry on task performance. In addition, the current experimental work is investigating if increased level of visual complexity of stimuli is playing a role in this interplay. Moreover, the novel pupil dilation measures are expected to reveal new information contributing to the understanding of the mechanisms behind the relations between cognition and worry. Generally, pupil size is believed to be influenced by such factors as anxiety and stress (e.g., Kahneman, 1973, Karatekin et al., 2003) while changes in pupillary measures during task performance are linked with the amount of cognitive effort (e.g., Beatty, 1982; Kahneman & Beatty, 1966).

A better understanding of the cognitive processes and the role of perceptual visual information that may be affecting the downregulation of adverse effects of worry may have

valuable clinical applications and may add to the development of tailored relief techniques for patients suffering from pathological worry and generalized anxiety disorder.

State of the Art

Attentional Processes and Executive Functioning

In general, the mechanisms of attention are considered responsible for allocating resources to perceptual or cognitive processing and are referred to as the “processes of selection and loss” (Remington & Loft, 2015) as well as “a state of focused awareness on a subset of the available perceptual information” (Gerrig, Richard, & Zimbardo, 2002). Moreover, attentional resources are generally considered to be limited, therefore selection and processing of information is believed to occur at the expense of other information (e.g., Broadbent, 1958; Lavie, 2004; Pashler, 1998; Treisman, 1964;).

Attentional processes are known to play an important role in cognition, such as working memory and executive functioning. The term executive functioning is defined in terms of processes related to goal-directed behaviour. Miyake et al. (2000) indicates three distinct subcomponents of executive functioning: inhibition, shifting and updating. Updating is defined as the ability to manipulate actively relevant information, including monitoring incoming information and revising items currently held in working memory as well as replacing no longer relevant information with new items (Miyake et al., 2000). Inhibition refers to the ability to inhibit responses when necessary and to protect working memory from distractors (Miyake et al., 2000). The shifting function is allocating attention to the task demands or stimuli that are currently most relevant (Eysenck & Derakshan, 2011; Miyake et al., 2000).

Another relevant cognitive function for the purposes of the present experimental work is ‘maintenance’ - defined as an active representation of an object, sound or object’s location in working memory (Baddeley, 2007). Maintenance is considered to interact with executive

functioning (Baddeley & Hitch, 1974; Baddeley, 2007). Maintenance can be defined in terms of domain specific processes, e.g., short term visual or phonological information storage (Baddeley, 2007) while executive functioning is believed to be domain general and to manage maintenance processes (Martini et al., 2015).

Worry and Anxiety

Worry is a defining feature of most anxiety-based disorders, such as different phobias, health anxiety or obsessive-compulsive disorders, as well as it is a central component of generalized anxiety disorder (American Psychiatric Association, 2013). Worry is defined as “a chain of thoughts and images, negatively affect-laden and relatively uncontrollable” (Davey & Wells, 2006, p. 3), including anxious apprehension for future and negative events (Barlow, 2002) that involves “a predominance of negatively valenced verbal thought activity” and minimal levels of imagery (Borkovec, Ray, & Stober, 1998, p. 562; Davey & Wells, 2006, p 3). Anxiety is a broader concept that incorporates worried thoughts, feelings of tension and physical changes (American Psychiatric Association, 2013).

Research concerning relations between anxiety and cognitive performance has focused on both state and trait anxiety (e.g. Clarke & Johnstone, 2013; Patel et al., 2015; Vytal et al., 2012). Trait anxiety is defined as a personality dimension and refers to a tendency to experience worry and negative affect such as fear and anxiety across different circumstances (David, 2013, Spielberger, 1983). State anxiety refers to anxiety levels in an individual at a particular moment (Spielberger, 1983). State and trait measures of anxiety are highly correlated and people who score highly on trait measures of anxiety tend to show more state anxiety in different situations (Bishop, 2008).

Relations between Cognitive Functioning, Worry, and Anxiety

Most of the theories and research that attempt to explain and investigate the interconnection between anxiety, worry and cognitive processing are based on the notion of

competition for resources, i.e., worrisome thoughts may use up attentional resources and leave fewer resources needed for a task at hand (e.g., Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011; Vytal et al., 2012). One of the most influential theories called Attentional Control Theory (Derakshan & Eysenck, 2009), states that increased difficulty in cognitive tasks requiring central executive function affects performance of individuals suffering from anxiety in a negative manner. With increased difficulty, anxious individuals are not able to compensate for resources already depleted by anxiety (Derakshan & Eysenck, 2009).

According to attentional control theory, anxiety impairs the ability to control information processing by actively using central executive function (Eysenck, Derakshan, Santos, & Calvo, 2007). According to attentional control theory, anxiety impairs two executive functions – shifting to new stimuli or new task demands and inhibition of irrelevant stimuli, while the executive updating function is not affected by anxiety. The authors argue that updating mostly involves temporary storage of information and therefore is mostly concerned with memory functions, rather than attentional resources per se (Derakshan & Eysenck, 2009).

According to attentional control theory, anxiety does not affect processing of visuospatial stimuli and may have minimal adverse effects on the processing of auditory stimuli (Eysenck & Derakshan, 2011). Worry is considered to involve inner verbal activity to a much greater extent than visual imagery (Davey & Wells, 2006). The attentional control theory states that worrisome thoughts interfere mostly with the allocation of attentional resources and not with the so called ‘visual sketchpad’ and ‘phonological loop’ (Baddeley, 2007; Eysenck et al., 2007). According to Baddeley’s model of working memory (Baddeley, 2007), the visuospatial sketchpad is responsible for maintenance of visual stimuli in working memory, whereas phonological loop is responsible for the storage and rehearsal of auditory and verbal stimuli. At least one experimental study (Rapee, 1993) has failed to reveal any

reliable relation between worry and a working memory task requiring solely the visuospatial sketchpad.

Anxiety and cognitive updating and maintenance functions. Generally speaking, research findings examining relations between anxiety, worry and cognitive updating function are often contradictory. In contrast to attentional control theory, there is evidence suggesting that pathological worry is associated with worse processing capacity in updating tasks (e.g., Gustavson & Miyake, 2011, 2016). For instance, Gustavson and Miyake (2016) found that trait worry negatively influenced reaction times in tasks requiring participants to remove items from working memory, which is a part of the updating function. In this respect, Gustavson and Miyake (2016) proposed an extension to ACT that updating functions are not immune to the effects of anxiety and worry.

In addition, a number of studies (e.g. Clarke & Johnstone, 2013; Patel et al., 2015; Vytal, et al., 2012; Vytal et al., 2013) have shown that state anxiety impairs performance in tasks involving the n-back paradigm that is widely believed to measure updating functions (Schmiedek et al., 2009). However, this negative effect of anxiety on task performance is only seen on easier levels of the n-back tasks (for more detailed information about the n-back paradigm, see the section “N-back and Reference-back Paradigms” below). With increased difficulty level, decrease in performance caused by state anxiety is alleviated (e.g. Clarke & Johnstone, 2013; Vytal et al., 2012). For example, Vytal et al. (2012) showed that the task performance was negatively affected by anxiety in verbal 1-back and 2-back tasks, but not 3-back tasks. They have also shown that in an induced anxiety condition, the level of anxiety measured by the magnitude startle reflex significantly decreased as task difficulty increased, suggesting that state anxiety was lower with increased task difficulty. In addition, Clarke and Johnstone (2013) showed that threat of shock interfered with performance in easier visuospatial n-back tasks, but this effect was absent with increased difficulty. Moreover, Patel

et al. (2015) showed that reaction times were faster in a threat condition than safe condition in verbal 3-back tasks, but did not reliably differ between these conditions for verbal 1-back and 2-back tasks, even though accuracy was lower for the 1-back and 2-back tasks in an induced anxiety condition. Likewise, Vytal et al. (2013) found that performance was diminished by anxiety in verbal 1-back and 2-back tasks, but did not differ for 3-back tasks.

The tasks within the n-back paradigm are complex and involve the use of several cognitive functions, among others, mental object maintenance (Kane, Conway, Miura, & Colflesh, 2007; Rac-Lubashevsky & Kessler, 2016), therefore it is not clear which cognitive functions may be responsible for the positive effects of engagement in more difficult n-back tasks during worry and anxiety. An attempt to understand further the relation between state anxiety and cognitive maintenance function was made by Balderston et al. (2016). The authors investigated effects of anxiety on maintenance function separately from executive functions. The results also showed that state anxiety did not reduce task performance in letter maintenance tasks, suggesting that only executive functions might be prone to negative effects of anxiety. These findings support attentional control theory. Moreover, the results showed that increased difficulty in these tasks, in fact diminished state anxiety. Likewise, King and Schaefer (2010) showed that emotional startle effect resulted from viewing negative pictures was disrupted when participants were introduced with a concurrent maintenance task, suggesting that working memory maintenance might reduce negative effect in general.

Limitations of the Existing Evidence and Scientific Impact of the Present Experimental Work

In the main, experimental work investigating relations between anxiety and executive updating used tasks utilizing the n-back paradigm (e.g., Clarke & Johnstone, 2013; Patel et al., 2015; Vytal, et al., 2012; Vytal et al., 2013). This paradigm is generally thought to measure the executive updating function, yet it necessarily involves mental maintenance, the

executive inhibition function and may involve different visual and verbal features of stimuli (Kane et al., 2007; Rac-Lubashevsky & Kessler, 2016). Therefore, it is hard to draw any direct conclusions about exactly which cognitive functions are responsible for diminishing anxiety and its negative effects on task performance and which functions are most negatively affected. The current experimental work aims to investigate further relations between worry and executive updating and working memory maintenance by both using the n-back paradigm and by separating load on the executive updating function from mental object maintenance using the reference-back paradigm (Rac-Lubashevsky & Kessler, 2016). Tasks within this paradigm are comparable to the n-back tasks, but at the same time allow for manipulation of perceptual load on maintenance function independently of updating function. The results will help to clarify if maintenance could be mainly responsible for alleviating effects of task engagement in the n-back tasks. Furthermore, pupillometry provides continuous measures of both arousal levels and the usage of attentional resources (e.g. Kahneman, 1973), and may therefore reveal supplementary information about cognitive processing patterns in both ‘worry’ and ‘no worry’ conditions during updating and maintenance trials. In addition, considering that such a measure does not require any overt responses and can be used to collect data in all stages of the n-back and reference-back tasks, it might be particularly revealing when attempting to disambiguate maintenance and updating functions.

Furthermore, the findings of different studies using either visuospatial or verbal stimuli when investigating relations between worry, anxiety and cognitive functions tend to be blended together to describe more general effects. The current experimental work focuses on visuospatial tasks in attempt to explore possible effects of worry on the visual sketchpad separately from the phonological loop as much as possible. By adding perceived visual complexity of stimuli as one of the experimental manipulations, the current experimental

work is the first to explore the possibility that visual properties of stimuli might modulate relations between worry, updating, and maintenance functions.

There is also a lack of experimental work examining how cognitive functioning is effected by state worry as compared to studies examining effects of trait worry and generalized anxiety disorder on cognitive functioning (e.g., Bishop, 2008; Gustavson, & Miyake, 2016). In this respect, the present experiment will contribute to current knowledge by utilizing an induced ‘worry’ condition.

Visual Perceptual Load and Distractor Interference

Investigation of effects of different levels of perceived visual complexity of stimuli on relations between worry, maintenance and updating functions was inspired by Lavie et al.’s (2004) load theory of selective attention and cognitive control, and by current theories of attention proposing multiple attentional resources (e.g., Pashler, 1998).

Load Theory (Lavie et al., 2004) states that increasing visual perceptual load diminishes distractor interference whereas increased cognitive task difficulty increases the interference. Operationally, higher visual perceptual load is defined as an increase in the difficulty of visual processing requirements of a task or as an increase in number of items or units in a display (Lavie, 1995). According to Lavie et al. (2004), the executive inhibition function is affected negatively by increased cognitive task difficulty. Increased difficulty in cognitive tasks drains cognitive resources needed for inhibition and, in this way, increases distractor interference. In contrast, perceptual visual load shields from distractor interference by affecting working memory passively, i.e., by consuming available resources so that there is no capacity left for the perception of distractors and distractors are not interfering with the task performance (Lavie et al., 2004).

The load theory has not yet been directly applied in the research domain of anxiety; however, considering worrisome thoughts as distractors, increased visual perceptual load may

affect the interference of worry during task performance. The experimental research investigating application of this theory to emotional distractors (Gupta, Hur, & Lavie 2016; Lavie & Fox, 2000; Molloy, Lavie, Chait, & Griffiths, 2015) and mind wandering (Forster & Lavie, 2009) gives promising results and unveil the potential that this theory may have in relation to worry and anxiety. For example, Forster and Lavie (2009) explored the role of visual load in determining susceptibility for distraction from internal task unrelated thoughts – mind wandering. They found clear effects showing that higher perceptual visual load, as compared to low visual load, diminished mind wandering. In addition, Gupta et al. (2016) found that increased perceptual load led to diminished interference of distractors with negative emotional valence. Collectively, these results indicate that increased visual perceptual load may lessen interference of worrisome thoughts on task performance.

N-back and Reference-back Paradigms

Taken together, tasks within the n-back and reference-back paradigms measure working memory constructs related to executive updating and maintenance functions as well as inhibition and recognition under interference (Kane et al., 2007; Rac-Lubashevsky & Kessler, 2016). The use of the reference-back tasks gives an opportunity to separate the executive updating function from the maintenance function (Rac-Lubashevsky & Kessler, 2016). For instance, when carrying out tasks within the n-back paradigm, participants are required to decide whether the presented item is the same or different from the one that was presented n-trials before and, in addition, to memorize the currently shown stimulus. In contrast, tasks within the reference-back paradigm are composed of two types of trials: reference trials and comparison trials. Participants are required to update their working memory with stimuli presented during the reference trials. During the comparison trials, participants are requested to determine if the present stimulus matches the one presented during the last reference trial. Between a reference trial and a matching picture, participants

are required to maintain stimuli in their working memory to complete this task. Only the reference trials require working memory updating whereas comparison trials require matching, inhibition and maintenance (Rac-Lubashevsky & Kessler, 2016). A comparison of cognitive functions involved in carrying out the n-back and reference-back tasks are detailed in Table A1, Appendix A.

In summary, the combination of the reference-back and n-back tasks that was chosen for the current experiment may reveal if increased maintenance function alone is enough to minimize possible effects of worry on task performance and if this function may be responsible for alleviating effects of increased difficulty in solely n-back tasks. Moreover, the results of performance during both the reference-back tasks and the n-back tasks with stimuli of two different visual complexity levels may help to see if visual complexity will change the dynamics in the relation between worry and cognition that was found in previous research. This information may benefit designs of future experimental works.

Predicted Results

The following hypotheses follow on from the experimental work reviewed:

1) Reaction times will be slower and proportion of correct answers will be lower in the 'worry' condition than in the 'no worry' condition in the n-back tasks. These differences will be more expressed in easier n-back tasks (n-back tasks with level 1 of n, n1) than in more difficult n-back tasks (n-back tasks with level 2 of n, n2).

2) Only minor differences between the 'worry' and 'no worry' conditions are predicted in the reference-back tasks. Increased load on maintenance should shield from possible negative effects of the worry induction. In this respect, performance in longer maintenance task (r2) should have lesser differences between the 'worry' and 'no worry' conditions than performance in shorter maintenance tasks (r1).

3) Increased visual perceptual load will lessen possible differences in task performance between the 'no worry' and 'worry' conditions.

4) Pupil dilation data will reveal differences in processing demand between the 'worry' and 'no worry' conditions indicating higher cognitive effort in the 'worry' condition. Different pupil dilation patterns during trial types requiring different cognitive functions in both n-back and reference-back tasks are predicted.

Methods

Participants

Twenty-two participants between the ages 19 and 43 years (mean 26 years) - took part in the experiment. All participants reported normal or corrected-to-normal vision. Participants were informed not to take part if they were suffering from generalized anxiety disorder or were in a distressing life situation.

Apparatus

Experimental tasks, instructions and stimuli were presented in a Dell Optiplex 755 (Dell Inc., Round Rock, Texas) personal computer equipped with a RED 500 (SensoMotoric Instruments of Germany (SMI), Teltow, Germany) eye tracking system. Stimulus presentation and timing were controlled using PsychoPy v.1.85.1 application (Peirce, 2007). Pupil dilation was recorded using SMI iView© X 2.7 software at 500Hz.

Visual stimuli were presented on a 22-inch Dell video monitor (Dell Inc., Round Rock, Texas). Participants were seated 70 centimetres from the video monitor and responded using the spacebar key of a mechanical computer keyboard. Calibration and validation of gaze data was conducted prior to each participant's experimental session and was repeated until the deviation scores were below an error of 0.5° both horizontally and vertically.

All participants were tested individually in a quiet testing room, and all questionnaires were presented on paper and completed using a standard ink pen.

Design

Each participant took part in the ‘worry’ and ‘no worry’ experimental conditions in one experimental session. In both conditions, the participants carried out two series of the n-back (1-back (n1), 2-back (n2)) and two series of the reference-back (r1, r2) tasks. Stimuli of two different levels of perceived visual complexity were presented in each task.

Participants were presented with fifteen practice trials for each task in the beginning of the experiment. The number of trials in each experimental condition is presented in Table 1 below.

Table 1.

The number of trials per participant in each experimental condition for each task.

Condition	Complexity level	Task			
		N1	N2	R1	R2
No worry	Low complexity	90	90	76	104
	High complexity	90	90	76	104
Worry	Low complexity	90	90	76	104
	High complexity	90	90	76	104
Total		360	360	304	416

The sequence of the experimental ‘worry’ and ‘no worry’ conditions, an order in which the tasks and stimuli of different perceived visual complexity were presented, were randomized and assigned for each participant individually.

Tasks. In the 1-back task, the participants were asked to remember the last picture presented while in the 2-back task participants were required to remember a picture presented two trials before. In both tasks, the memorized picture needs to be compared with a currently shown stimulus. The 1-back and 2-back tasks are illustrated in Figure 1 below.

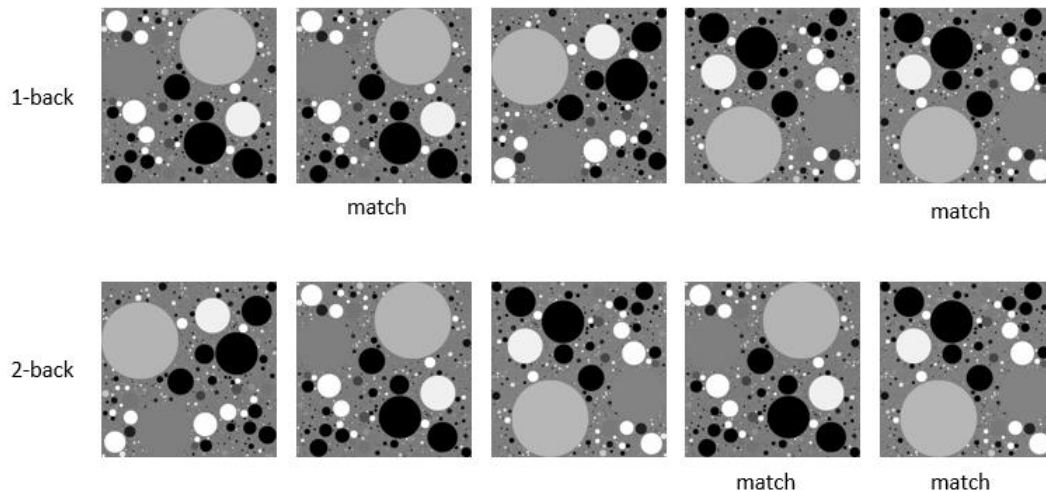


Figure 1. An illustration of the 1-back and 2-back tasks. Each stimulus was presented for 2.5 seconds and a blank grey screen was presented for 0.5 seconds between the stimuli.

During the reference-back tasks, stimuli in reference trials were presented in a white frame. Participants were asked to remember these stimuli and to compare them with all the subsequent pictures without any frame (comparison trials). Participants were asked to respond when they saw the same picture as the last one in a white frame, just without a white frame.

The difficulty level in the reference-back task was manipulated by increasing the period during which participants were required to maintain stimuli features in their working memory, i.e. increasing the number of comparison trials between the reference stimulus and matching stimulus. During the reference-back tasks with a shorter maintenance period, the participants were introduced with three comparison trials before each matching picture, resulting in a maintenance period of 9.5 seconds. The longer maintenance period included six comparison stimuli between a reference trial and a matching stimulus leading to a maintenance period of 18.5 seconds. An illustration of the reference-back task with three comparison trials between reference trial and a matching picture is presented in the Figure 2

below.

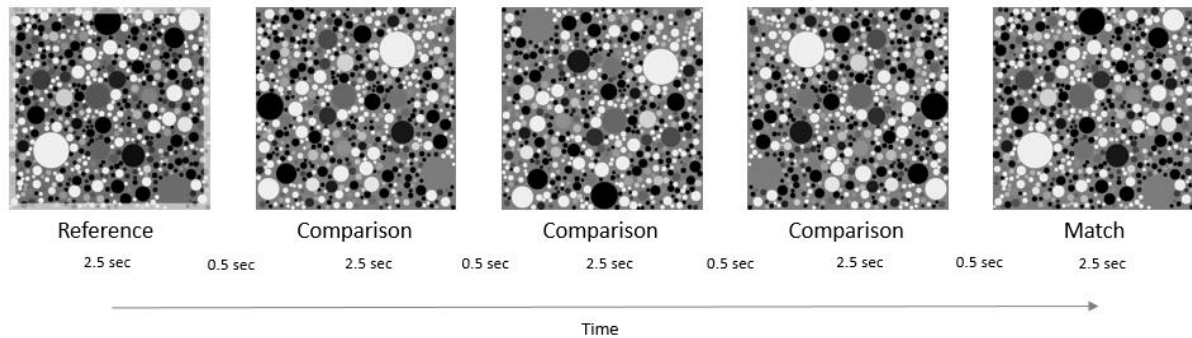


Figure 2. An illustration of the reference-back task with three comparison trials between a reference trial and a matching stimulus. Each stimulus was presented for 2.5 seconds and a blank grey screen was presented for 0.5 seconds between the stimuli.

To address a possibility that participants could learn the number of comparison trials between a reference trial and a matching stimulus in each difficulty level in reference-back tasks, and in this respect, respond by counting instead of recognizing, sequences with different numbers of comparison trials (from none to nine) were randomly included in both the r1 and r2 tasks. These sequences constituted up to twenty-five percent of all the trials. Data from these sequences was discarded from the analyses and these sequences were not included in the number of trials in Table 1.

‘Worry’ and ‘no-worry’ conditions. In the beginning of the ‘worry’ condition, the participants were asked to identify one personally relevant situation that worries them the most in their current everyday life. This method is a commonly used strategy to induce worry (e.g. Sari et al., 2016; Stefanopoulou, Hirsch, Hayes, Adlam, & Coker, 2014). The participants were given two minutes to write down thoughts related to this topic on a blank sheet of paper. The participants were notified that these notes are solely meant to help to concentrate on a worrisome topic and that the experimenter will not read or take these notes. Before each task was presented, the participants were instructed to think about their chosen worrisome topic in a usual manner. During this time, a blank computer screen was shown.

After fifteen seconds, the first sequence of tasks started. The sequence of instructions in the ‘worry’ condition is presented in the Figure 3 below.

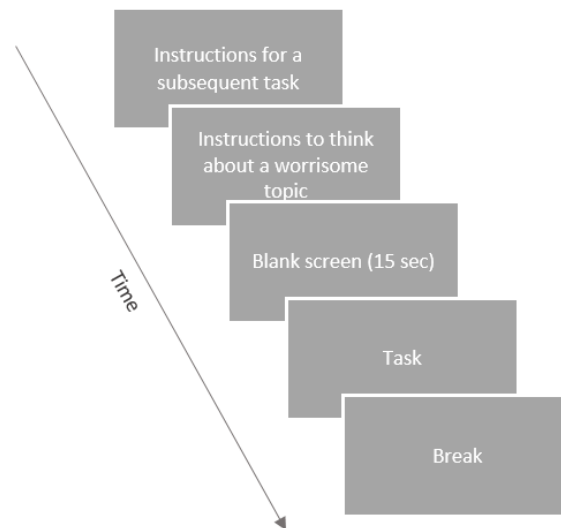


Figure 3. An illustration of a sequence of instructions preceding each task in the ‘worry’ condition.

During the ‘no worry’ condition, instead of thinking about a worrisome topic, participants were asked to remember and to think about a leisure activity or a hobby that they enjoy doing. The sequence in which instructions before each task were presented mirrored exactly the sequence in the ‘worry’ condition.

Stimuli

Forty-eight different grayscale geometric patterns were used as stimuli in the present experiment. Stimuli were generated by Yağmur, Hubertus and Evan (2016) using a statistical space filling algorithm (Shier, 2011; Shier & Bourke, 2013). This algorithm fills the space with randomly placed non-overlapping geometric shapes that gradually decrease in size. This particular set of stimuli was chosen for the current experimental work, because it provided a clear division between the levels of visual complexity and included ratings of perceived levels of visual complexity made by thirty participants (Yağmur et al., 2016).

Stimuli of two different, relatively distant, levels of perceived visual complexity were chosen from the original stimuli set (Yağmur et al., 2016). Geometrical shapes used in the current experiment included circles, squares and hexagons. The examples of stimuli of two different levels of perceived visual complexity that were used in the current experiment are presented in Figure 4 below. A mean distribution of brightness values across the layer of the stimuli, a background screen and a screen presented between the stimuli were adjusted and equalized to the mean value of 125 cd/m². Stimuli sets including different geometrical shapes were randomly assigned to each participant individually.

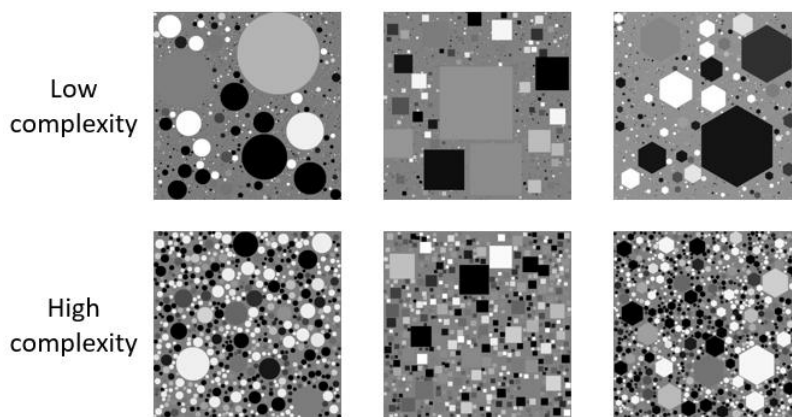


Figure 4. An example of stimuli sets of two different perceived complexity levels used in the current experiment.

Procedure

The participants were invited to come to a laboratory at the university campus. During the experiment, the participants were presented with written task instructions on a computer screen. The participants had a possibility to ask questions regarding the tasks during the learning period or during the breaks between the sessions. The experiment included three short breaks in each experimental condition ('worry', 'no worry') and one longer break between the conditions. Participants were able to decide the length of the breaks. On average, the experimental session took one and a half hour, including practice trials and breaks.

After carrying out the tasks in each experimental condition, the participants were asked to rate their mood using a questionnaire consisting of six items. They were asked to indicate how calm, tense, upset, relaxed, content and worried they have felt. Each item was rated on a four-point Likert scale ranging from 1, indicating “not at all”, to 4, indicating “very much”. The questionnaire used in the current experiment is a shortened version of the State-Trait Anxiety Inventory’s (STAI) state anxiety scale (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; Spielberger, 1989) developed by Marteau and Bekker (1992). This short version of the STAI has proven to show a robust relationship with the full twenty-item scale, showing correlation $r > .90$ (Marteau & Bekker, 1992; Tluczek, Henriques, & Brown, 2009). A reliability coefficient for the shortened scale is $\alpha = .82$. (Marteau & Bekker, 1992).

After filling in the shortened version of the STAI questionnaire, the participants were asked to rate their effort in thinking worrisome thoughts and thinking about an activity that they enjoy doing. The scale included two items. The first item asked to indicate how much effort participants needed to start to think about an activity or a worry, while the second item was asking how much effort participants needed to start to think about it again when asked before each task. Items were rated on a four-point Likert scale ranging from 1, indicating “not at all”, to 4, indicating “very much”.

Ethical issues. This experimental work was carried out in accordance with the rules and regulations laid down by the Ethics Committee for the Swedish Research Council. All participants gave written informed consent in accordance with the Declaration of Helsinki.

None of the experimental tasks included any form of deception. The tasks and questionnaires that were applied in the current experimental work are widely used in psychological research and are not harmful to participants. However, the task to think about a personal situation that worries the participants could have possibly led to changes in participants’ mood. For this reason, during the recruitment phase, all potential participants

were provided with extended information about the experiment, including information that they will be asked to remember and to think about a situation that worries them in their current everyday lives the most. Potential participants were asked not to participate in the experiment if they believed that this task could cost any additional discomfort or distress or if they were suffering from generalized anxiety disorder. Each potential participant had an opportunity to read more about the experiment and to ask questions during the recruitment phase. All participants were informed about an option to withdraw from the experiment at any time, without giving any reason.

Furthermore, after the experimental session, the participants were provided with a full disclosure and were able to stay longer and to ask questions about the experiment. In addition, they were handed debriefing sheets with extended information about the purposes behind the experimental work, contact details of the researcher and information about worry and anxiety. Contact details for local health centres helping to deal with psychological issues were included in the participant debriefing sheets.

Data obtained during the experiment was coded numerically and there was no possibility to connect it to participants' names. No other data concerning participants' personal information was maintained.

Pupil dilation

To complement behavioural data, pupillary responses were used as one of the dependent variables in the current experimental work. Pupil dilation has been shown to reflect "cognitive effort" or the "usage of attentional resources" in numerous studies (e.g., Beatty, 1982; Kahneman & Beatty, 1966). In addition, changes in pupillary sizes have low latency with respect to changes in processing demand, i.e., changes in pupil size are observed immediately after introducing changes in task demand and therefore this method is thought to be a reliable index of cognitive effort both within and across tasks (Beatty, & Lucero-

Wagoner, 2000). Adding pupillary data to behavioural response time and binary choice data gives an opportunity to collect outcome data in all stages of a task, regardless of response. Moreover, pupillary data may also serve as a validation for worry induction. Tonic (baseline) changes in pupil size are associated with emotional arousal, while phasic changes occur due to variations in task demands, i.e. the pupil dilates in accordance with cognitive effort (Karatekin, Couperus, & Marcus, 2004). In summary, this novel method may provide for empirical assessment of differences in processing demand regarding both increased task difficulty on maintenance and updating functions in both ‘worry’ and ‘no worry’ experimental conditions.

Data Analysis

Data reduction and pre-processing of pupil data. The collected pupil data was pre-processed using in-house software written in MATLAB 7.4 (The Mathworks, Inc., Natick, MA) as provided by R. Johansson, 2016. To correct for blinks and missing data all samples of zero data was discarded, including the 10 preceding samples and the 10 following samples. To correct for physiologically implausible values, samples with data below 1 mm or above 9 mm were also discarded. Linear interpolation was performed to correct the data for such exclusions on the basis of the first and last good data point. To reduce high frequency noise, the data was filtered using a 10 Hz low-pass filter. To capture changes in pupil diameter during a trial, the average pupil diameter of the last 200 ms from the preceding baseline screen was subtracted from each sample in each condition.

Analysis. Data analysis was conducted in five parts. First, following the recommendations made by Ratcliff (1993) and Whelan (2008), all reaction times (RT) were transformed to response speed (RS) by inversion ($1/RT$). This method reduces the usual skew of RT distributions and reduces effects of slow reaction times, which can thwart subsequent analysis (Ratcliff, 1993; Whelan, 2008). Only response data from correct trials were included

in the response speed analyses. Then relations between the RS and proportion of correct responses were examined to determine if there were any speed-error trade-offs in each condition. This was done by standard linear regression of RS on logit P, where logit P is the log odds ratio of p - the proportion of correct responses: $\text{logit } P = \log_e[p/(1-p)]$.

Second, Generalized Linear Mixed Effects Modeling (GLMM) was used to examine the binary response data. A binomial distribution and logistic link was applied in the analyses. For this analysis, condition ('worry', 'no worry'), visual complexity (high, low), and task (n1, n2, r1, r2), were entered as fixed effects, dummy coded, along with the 4 interactions 1) condition and visual complexity, 2) condition and task, 3) visual complexity and task, 4) condition, visual complexity and task. Participants were entered with their own intercepts as well as by-participant random slopes for condition and task. The overall fit of each effect was assessed using p-values obtained by likelihood ratio test of the model with the effect, against the same model without the effect. There were no concerns about the assumptions underlying this test because logistic regression does not make many of the key assumptions underlying linear mixed effects modeling, such as linearity, normality, and homoscedasticity.

Third, the RS data was examined following the same approach used to analyze the binary response data using standard Linear Mixed Effects Modeling (LMM): condition ('worry', 'no worry'), visual complexity (high, low), and task (n1, n2, r1, r2), were entered as fixed effects, dummy coded, along with the 4 interactions 1) condition and visual complexity, 2) condition and task, 3) visual complexity and task, 4) condition, visual complexity and task. Participants and condition ('worry', 'no worry') were entered with their own intercepts. Further, inclusion of by-participant random slopes for condition and task resulted in problems associated with convergence and failed to improve model fit, as compared to the model described. No obvious deviations of linearity, homoscedasticity or normality were found, and

p-values were obtained by likelihood ratio tests of the model with the effect against the same model without the effect.

Fourth, three separate measures of pupil size were computed 1) average pupil diameter of the last 200 milliseconds from the preceding baseline screen, 2) mean pupil size deviation from the baseline (calculated by subtracting baseline measures from the pupillary diameters recorded during each trial), 3) mean pupil diameter for the fifteen seconds period before each task, during which each participant was asked to either generate a worrisome thought or think about a leisure activity or a hobby that they enjoy doing.

Analyses using LMM for the pupillary baseline measures included: condition ('worry', 'no worry'), visual complexity (high, low), and task (n1, n2, r1, r2) as fixed effects, along with the 4 interactions 1) condition and visual complexity, 2) condition and task, 3) visual complexity and task, 4) condition, visual complexity and task. Participants and condition ('worry', 'no worry') were entered with their own intercepts as random effects; a random participant by condition slope was also included in the model.

LMM analyses were also used to examine pupil size data obtained during fifteen seconds' thought generation task and included condition ('worry', 'no worry') as fixed effect. Participants and condition ('worry', 'no worry') were entered with their own intercepts as random effects.

No obvious deviations of linearity, homoscedasticity or normality were observed, and p-values were obtained by likelihood ratio tests of the model with the effect against the same model without the effect in the analyses of the above mentioned pupil dilation measures.

All attempts to apply LMM to analysis of the mean pupil dilation deviation from the baseline data resulted in problems associated with convergence and were discarded. On these grounds mean pupil size deviation from the baseline data was analyzed separately using standard within participant's analysis of variance ANOVA with 4 within participant factors,

condition ('worry', 'no worry'), visual complexity (high, low), task (n1, n2, r1, r2) and trial type. Analyses of the n-back and reference-back tasks were conducted separately due to differences in trial types (correct rejection and correct answer in the n-back tasks; reference, comparison (correct rejection) and correct answer in the reference-back tasks).

Fifth, STAI questionnaire data was analyzed using LMM and included condition ('worry', 'no worry') as fixed effect. Participants and condition ('worry', 'no worry') were entered with their own intercepts as random effects. The same LMM model was applied to questionnaire data indicating effort needed to think about a worrisome topic or a leisure activity that participants enjoy doing. To meet the assumptions of the test, a logarithmic transformation was applied to the questionnaire data, and p-values were obtained by likelihood ratio tests of the model with the effect against the same model without the effect.

All data analysis was conducted using R (R Core Team 2017), together with the package lme4 (Bates, Maechler, Bolker, & Walker, 2015) for linear mixed effects modelling. The "bobyqa" optimizer (Powell, 2009) was used in GLMM analysis of the binary response data to resolve problems associated with convergence. All other LMM analyses use the "bobyqa" optimizer by default.

Results

Binary Choice and Response Speed

Linear regression of the RS on logit P revealed a close relationship between RS and logit P , $F(1, 14) = 14.99$, $p < .01$, Adjusted $R^2 = .48$. As shown in Figure 5 predicted RS is equal to $1.16 + 0.91 (\text{logit } P)$. In this respect, no noticeable speed-error trade-offs were found.

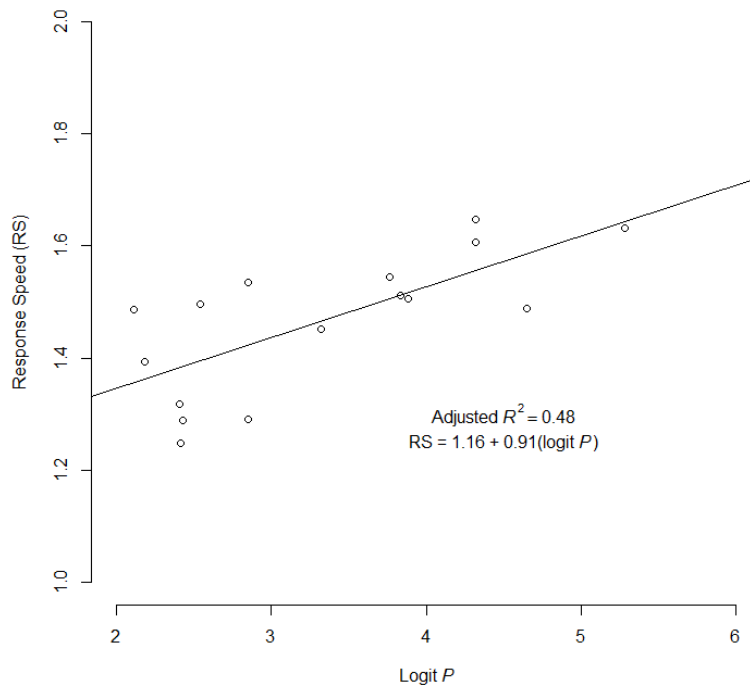


Figure 5. Relationship between RS for correct responses and logit P as revealed by standard linear regression of RS on logit P .

The proportion of correct responses for the ‘worry’ and ‘no worry’ conditions by task, and the proportion of correct responses for the high and low visual complexity stimuli by task are presented in Figure 6. Likelihood ratio tests of GLMM analysis of the binary response data revealed a statistically significant fixed interaction effect of condition, visual complexity, and task $\chi^2(3) = 20.14, p < .01$. No other fixed effects or fixed interaction terms were found to be statistically significant.

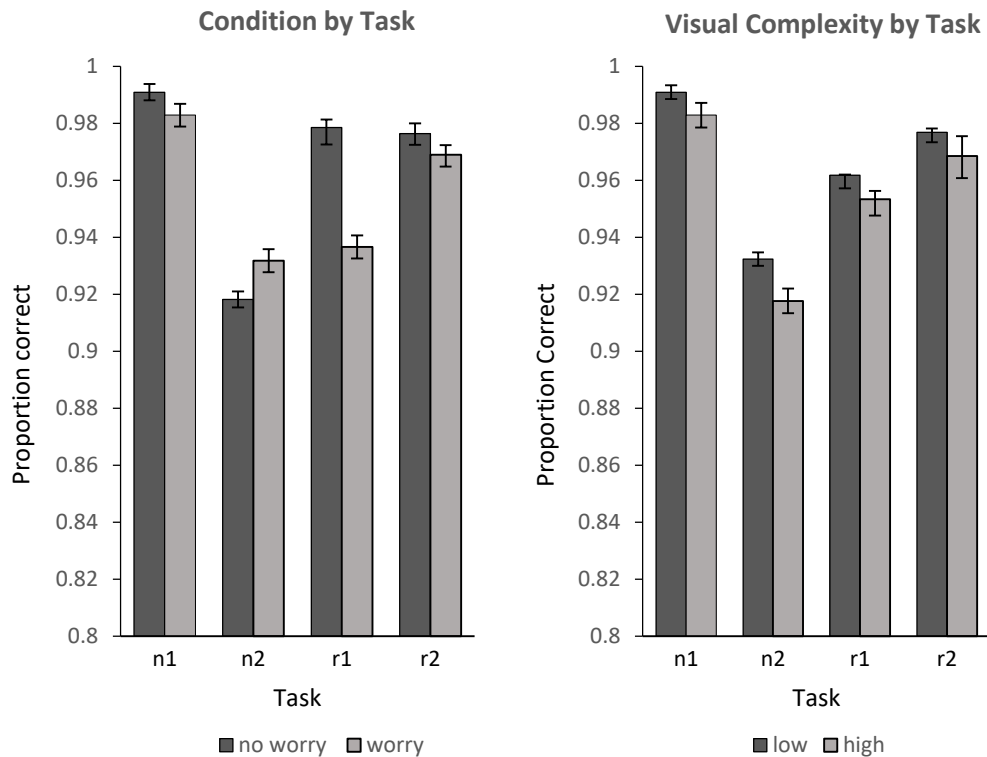


Figure 6. The proportion of correct responses for the ‘worry’ and ‘no worry’ conditions by task, and the proportion of correct responses for the high and low visual complexity stimuli by task. The standard errors bars show 95% confidence intervals.

Figure 7 shows mean RS for correct responses for the ‘worry’ and ‘no worry’ conditions by task, and the proportion of correct responses for the high and low visual complexity stimuli by task. In addition, Figure 8 graphically shows differences in the RS between the ‘no worry’ and ‘worry’ conditions for each combination of the task and visual complexity level. Likelihood ratio tests of LMM analysis of the RS data revealed a statistically significant interaction effect of condition, visual complexity, and task $\chi^2(3) = 9.16, p < .05$. No other fixed effects were found to be statistically significant.

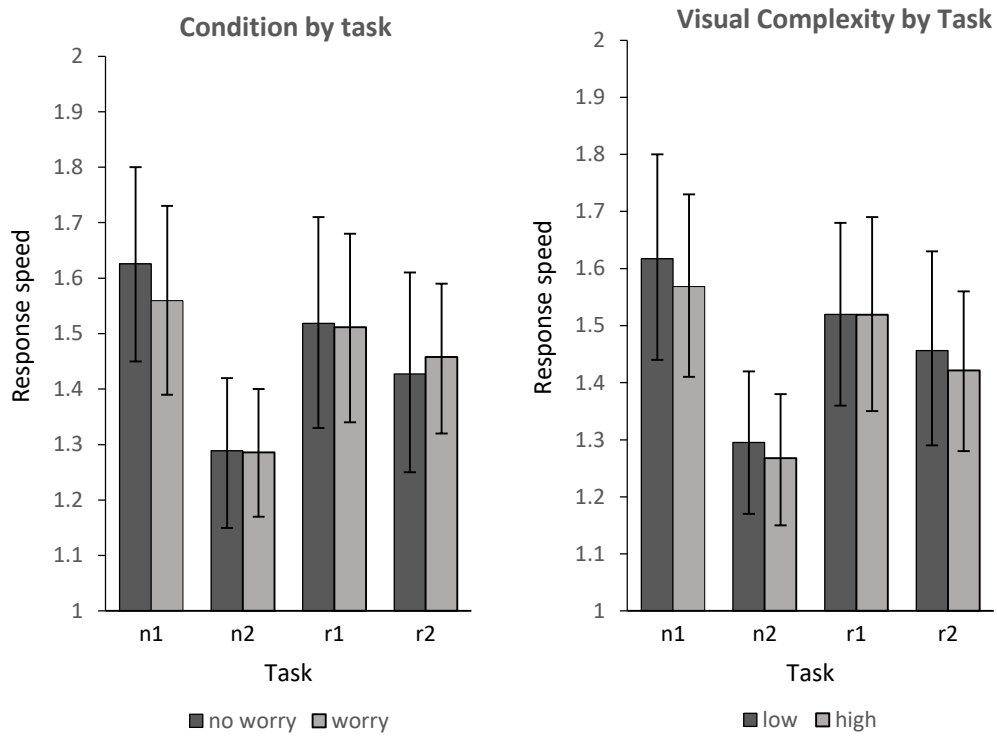


Figure 7. Mean RS for correct responses for the ‘worry’ and ‘no worry’ conditions by task, and mean RS for correct responses for the high and low visual complexity stimuli by task. The standard errors bars show 95% confidence intervals.

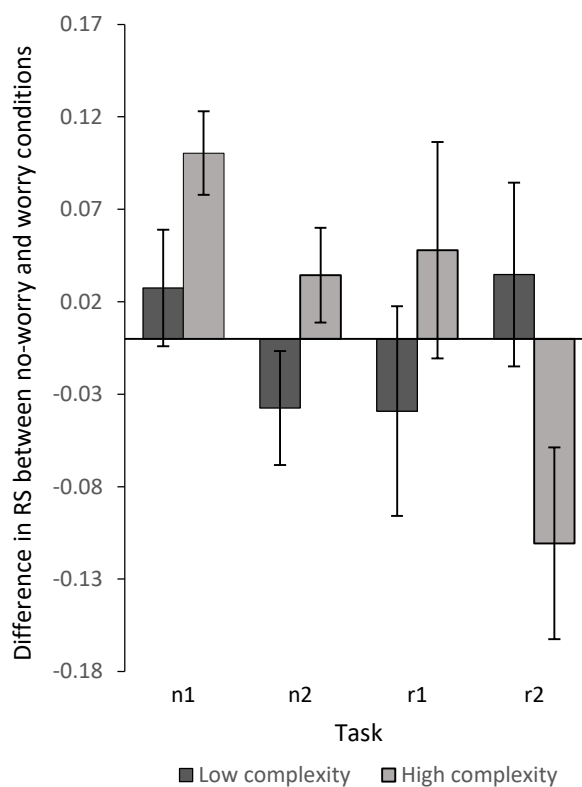


Figure 8. Differences in the RS between the ‘no worry’ and ‘worry’ conditions in each task and visual complexity level. Positive bars indicate combinations of the task and visual complexity levels in which participants were faster in the ‘no worry’ condition than in the ‘worry’ condition. Negative bars indicate tasks and visual complexity levels in which participants were slower in the ‘no worry’ condition than in the ‘worry’ condition. The standard errors bars show 95% confidence intervals. Figure is prepared according to Table B1, Appendix B.

In summary, visual examination of the binary choice data reveals higher accuracy level in the ‘no worry’ condition than in the ‘worry’ condition in all tasks except for the n2 task. The RS data indicate that participants were faster in the ‘no worry’ condition than the ‘worry’ condition in the n1 task. Participants were generally slower and less accurate with the stimuli of high visual complexity than with stimuli of low visual complexity.

Pupillary data

Mean pupil size deviation from the baseline. Figure 9 illustrates mean pupil diameter deviation from the baseline during the correct rejection and the correct answer trials in the n1 and n2 tasks. Within participants analysis of variance of the mean pupil size deviation from the baseline data in the n-back tasks revealed statistically significant fixed effects of trial type (correct rejection, correct response), $F(1,20) = 44.49, p < .01$, and visual complexity, $F(1,20) = 7.14, p < .05$.

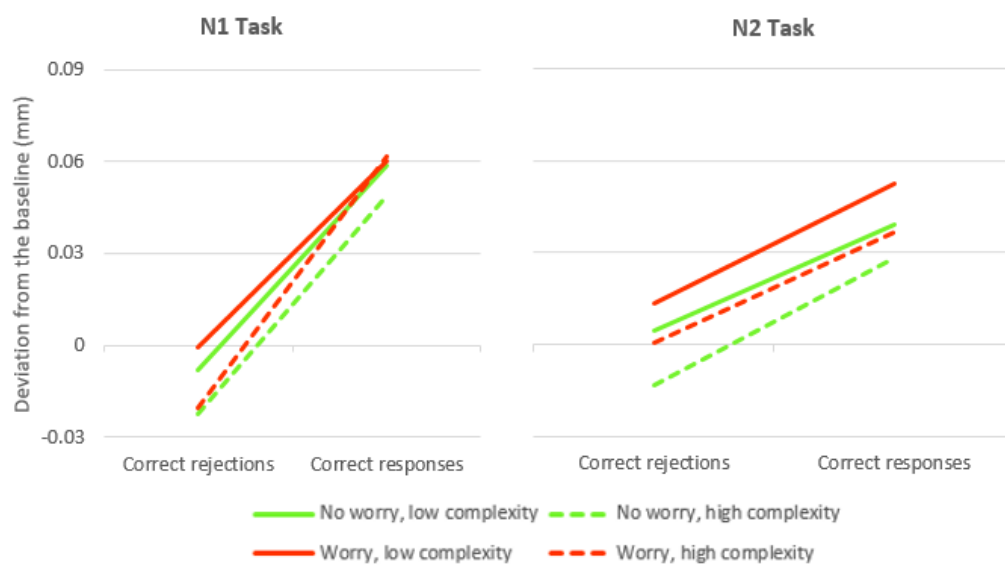


Figure 9. Mean pupil diameter deviation from the baseline (in millimeters) during the correct rejection and correct answer trials in the n1 and n2 tasks.

Figures 10 and 11 illustrate mean pupil diameter deviation from the baseline during different trials in the r1 and r2 tasks. Within participants analysis of variance of the mean pupil size deviation from the baseline data in the reference-back tasks revealed statistically significant fixed effects of trial type (reference, comparison (correct rejection), correct response), $F(2,40) = 26.54, p < .01$, and fixed interaction effects of visual complexity and trial type, $F(2,40) = 4.76, p < .05$, as well as task and trial type $F(2,40) = 4.54, p < .05$.

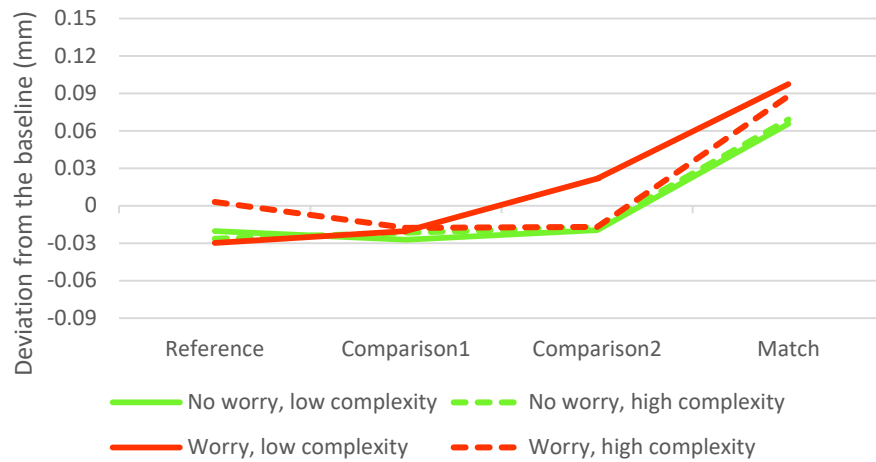


Figure 10. Mean pupil diameter deviation from the baseline (in millimeters) in the r1 task.

An outline of the r1 task.

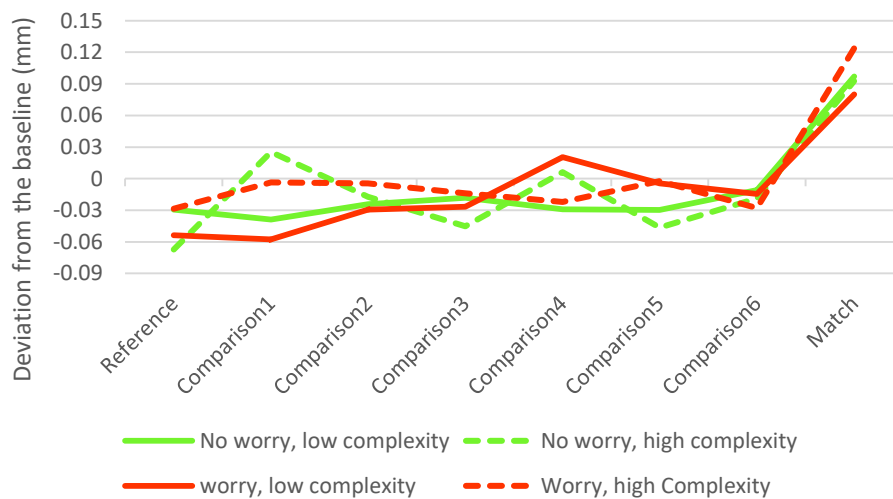


Figure 11. Mean pupil diameter deviation from the baseline (in millimeters) in the r2 task.

An outline of the r2 task.

To examine further the differences between separate trial types in both the n-back and reference-back tasks, figures illustrating mean pupil diameter deviation from the baseline during the full length of trial were aggregated. For more information and visual presentation of the changes in mean deviation from the baseline during different types of trials see Figure C1, Appendix C.

Pupillary baseline measures. Likelihood ratio tests of LMM analysis of pupillary baseline data revealed a statistically significant interaction effect of condition, visual complexity, and task $\chi^2(3) = 54.2, p < .001$. No other fixed effects or fixed interaction terms were found to be statistically significant. The baseline pupil sizes in the ‘worry’ and ‘no worry’ conditions by task, and the baseline pupil sizes in the high and low visual complexity conditions by task are presented in Figure 12 below.

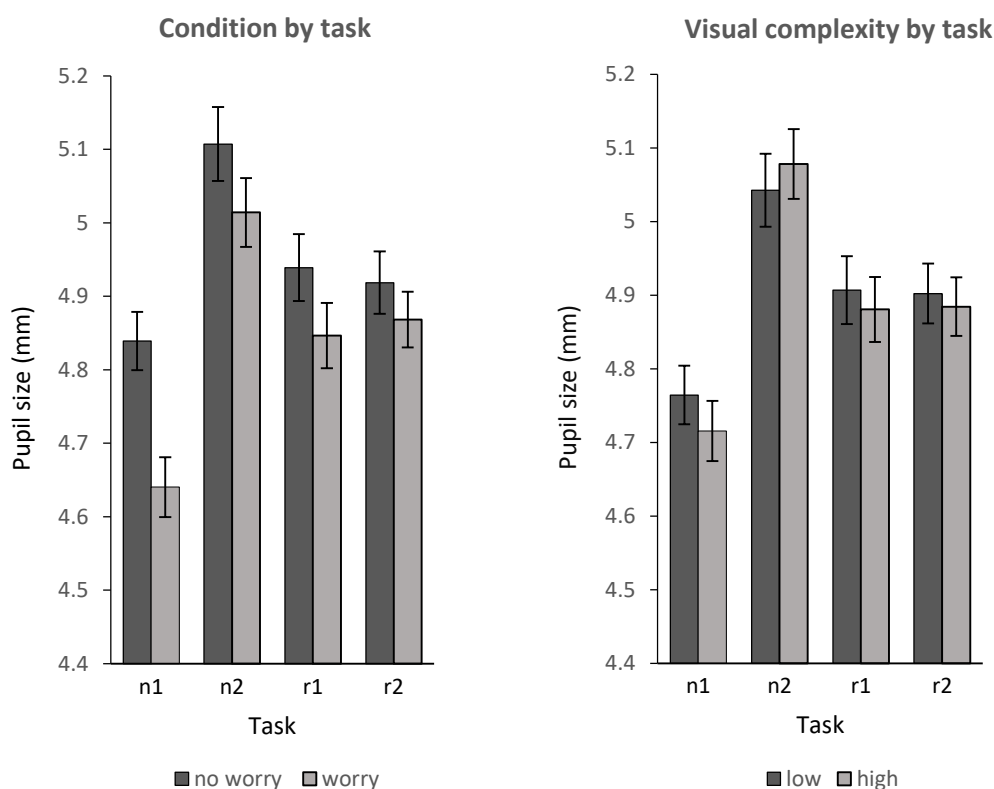


Figure 12. Baseline pupil sizes (in millimeters) in the ‘worry’ and ‘no worry’ conditions by task, and the baseline pupil sizes in the high and low visual complexity conditions by task.

Mean pupil size measures obtained during the 15 seconds of active thinking about either a worrisome topic or a leisure activity that participants enjoy doing showed smaller mean pupil diameter in the ‘worry’ condition ($M=4.85\text{mm}, SD=0.78$) and larger mean pupil diameter in the ‘no worry’ condition ($M=4.96\text{mm}, SD=0.89$). However, likelihood ratio tests of LMM analysis of these measurements did not reveal a significant fixed effect of condition.

In summary, pupil dilation data showed higher deviation from the baseline in the ‘worry’ condition than in the ‘no worry’ condition and generally smaller pupil diameter measures in the ‘worry’ condition than in the ‘no worry’ condition.

Questionnaire data

LMM analysis of the results of the State-Trait Anxiety Inventory’s (STAI) state anxiety scale and the questionnaire indicating level of effort needed to think about either a worrisome topic or a leisure activity showed no statistically significant effect of condition. Mean scores indicated higher state anxiety in the ‘worry’ condition ($M=14.05$, $SD=2.17$) than in the ‘no worry’ condition ($M=13.41$, $SD=1.89$). Mean score results of the effort questionnaire indicated higher effort in thinking about a worrisome topic ($M=4.73$, $SD=2.56$) than about a leisure activity ($M=3.68$, $SD=2.68$).

Discussion

General

The present experimental work investigated relations between the ‘worry’ and ‘no worry’ conditions and increased difficulty in tasks within the n-back and reference-back paradigms as well as the role of the level of perceived visual complexity of stimuli in this interplay. Analyses of the response speed (RS) and binary choice data revealed significant interaction effects between the condition (‘worry’, ‘no worry’), task (n1, n2, r1, r2) and the level of perceived visual complexity of stimuli (low, high).

Generally, the RS results were as predicted for the n1 and n2 tasks, showing slower RS in the ‘worry’ condition in the n1 task and almost no difference between the conditions in the n2 task (Figure 7). A similar pattern followed in the results of the binary choice data, showing smaller proportion of correct answers in the ‘worry’ condition in the n1 task and even higher proportion of correct answers in the ‘worry’ condition than in the ‘no worry’ condition in the n2 task (Figure 6). These results are in line with the previous research,

showing that worry and anxiety do not interfere or interfere less with performance in more difficult n-back tasks (e.g., Clarke & Johnstone, 2013; Vytal, Cornwell, Arkin, & Grillon, 2012). Results of the analyses of the RS in the r1 and r2 tasks were also according to the predictions prior to the experiment. The RS in the r1 task did not differ between the ‘worry’ and ‘no worry’ conditions and the results of the RS in the r2 task showed slightly faster reaction times in the ‘worry’ condition (Figure 7).

Taken together, the RS results of the current experiment suggest smaller differences between the ‘no worry’ and ‘worry’ conditions during the tasks requiring longer mental object maintenance. This notion holds true for the both task paradigms. When increasing difficulty level in the n-back tasks, one of the functions of those demand increases is mental object maintenance; therefore, the shift from worse performance in the ‘worry’ condition to the equal performance in the both conditions may be related to the maintenance function. Moreover, no differences in the RS between the ‘worry’ and ‘no worry’ conditions in the reference-back tasks, which require primarily the same cognitive functions as the n-back tasks (see Table A1, Appendix A) with only the period of mental object maintenance increased, backs the notion that maintenance alone is enough to alleviate the differences between the ‘worry’ and ‘no worry’ conditions in the RS. However, the results of the binary choice data for the r1 task (Figure 6) showed a substantially lower proportion of correct answers in the ‘worry’ condition than in the ‘no worry’ condition, which was opposite to the predictions prior to the experiment. This result is showing that performance accuracy suffers in the ‘worry’ condition even though the response times in correct trials do not differ from the ‘no worry’ condition. With increased maintenance period in the r2 task, the difference in the accuracy level between the ‘worry’ and ‘no worry’ conditions became substantially smaller. This may indicate that possible effects of ‘worry’ on the performance accuracy may also be alleviated by increasing time of maintenance.

According to attentional control theory (Eysenck et al., 2007), maintenance and updating are not negatively affected by worry. The lower performance measures in the n1 tasks and r1 tasks in the ‘worry’ condition in the present experiment may be related to an impairment of the executive inhibition function, which is the most prone to the deteriorative effects of worry and anxiety as stated by attentional control theory.

Attentional control theory addresses the effects of anxiety on cognition; however, it does not directly undertake the findings of the studies showing alleviating influence of increased cognitive load on anxiety. An implication of this theory on the latter effect, proposed by Balderston et al. (2016), suggested that engagement of the central executive functions should mediate the effect of cognitive load on state anxiety. However, the authors found that this reasoning did not hold true and working memory maintenance alone was enough to suppress state anxiety and its effects on task performance (Balderston et al., 2016). The results of the current experiment are in line with these findings.

The Role of Visual Complexity

Statistically significant interaction effects that were found in the RS and binary choice data in the current experimental work show the importance of presented visual information in the relationship between the ‘worry’ and ‘no worry’ conditions and performance in the n-back and reference-back tasks. Considering previous research literature, this finding is novel. Visual examination of the differences in the RS between the ‘no worry’ and ‘worry’ conditions for each combination of the task and visual complexity level (Figure 8) reveals that the participants responded faster in the ‘no worry’ condition than in the ‘worry’ condition with both low and high visual complexity stimuli in the n1 task. However, this difference was substantially larger with the high visual complexity stimuli. Moreover, in the n2 and r1 tasks, the participants were faster in the ‘worry’ condition than in the ‘no worry’ condition with the low visual complexity stimuli and slower in the ‘worry’ condition than in the ‘no worry’

condition with the high visual complexity stimuli. These results indicate that increased visual complexity of stimuli had deteriorative consequences on the RS in the ‘worry’ condition, but not necessarily in the ‘no worry’ condition.

These results are opposite to the predictions prior to the experiment. According to load theory (Lavie, et al. 2004), increased visual load hinders distractor interference and recent research findings showed that increased load might hinder interference of inner semantic distractors, e.g., mind wandering (Forster and Lavie, 2009) or negatively valenced emotional distractors (Gupta et al., 2016). Considering these findings, it was predicted that increased visual load would reduce possible interference of worrisome thoughts by supposedly consuming more of the available resources, as stated in load theory (Forster and Lavie, 2009). However, this assumption did not prove to hold true in this experimental setting. The results of the RS and binary choice data of the current experiment are indicating that worry may put extra load on cognitive functions and this additional load might worsen the interference of irrelevant visual information during the task performance. These assumptions are in line with attentional control theory, stating that inhibition is affected by worry and that worry and anxiety is interfering with cognitive processing by causing a shift from directing attention based on current task goals and intentional plans (so called ‘top down’ attentional processes) to attention allocation based on externally driven factors and sensory processing of stimuli properties (so called ‘bottom-up’ attentional processes) (Eysenck et al., 2007). This shift is leading to competition for access to limited resources in working memory (Eysenck et al., 2007). Following these notions, the RS patterns showing negative impact of visual complexity on the RS in the ‘worry’ condition may indicate that irrelevant stimuli sensory information depleted attentional resources required for tasks in the ‘worry’ condition to a greater extent than in the ‘no worry’ condition. On the other hand, according to the perceptual load model (Lavie, 1995, 2005; Lavie, Hirst, De Fockert, &

Viding, 2004) and Pashler's uncontrolled serial model (Pashler, 1998), perception of visual stimuli proceeds in an automatic and involuntary fashion until all stimuli features are processed as long as there are any resources left and regardless if this information is required for the task at hand. These notions, combined with the processing efficiency hypothesis (Eysenck et al., 2007; Eysenck, & Derakshan, 2011), stating that worry and anxiety primarily affects processing speed, may imply that all stimuli features were processed in both the 'worry' and 'no worry' conditions, but the processing of stimuli was slower in the 'worry' condition.

Few previous studies investigating relations between anxiety and inhibition of salient non-emotional visual distractors showed that trait anxiety, but not state anxiety, was related to increased visually salient and emotionally neutral distractor interference (Moran & Moser, 2015) and that state anxiety increased in presence of irrelevant non-emotional distractors in individuals already scoring high in trait anxiety (Moser, Moran, & Leber, 2015). In respect to these findings, the current experimental work added that state worry might also increase the interference of irrelevant visual information.

Interestingly, in the 'no worry' condition, in the n2 and r1 tasks, the RS was slightly faster to high visual complexity stimuli than to low visual complexity stimuli (Table B1, Appendix B). Keeping in mind that the tasks within the n-back and reference-back paradigms require active inhibition function, increased visual load might have had a positive effect on distractor inhibition in the 'no worry' condition as stated in the load theory (Lavie, 1995). In addition, with increased maintenance period in the r2 task in the 'worry' condition, visual complexity of stimuli did not interfere with the task performance; instead, the RS was higher than with low visual complexity stimuli. However, neither of the latter connections can be tested further in this experimental setting and more research investigating these relations separately is needed.

Pupil dilation

Analyses of the the pupillary baseline measures revealed significant interaction effects between the condition ('worry', 'no worry'), task (n1, n2, r1, r2) and the level of perceived visual complexity of stimuli (low, high). Analyses of the pupil size deviation from the baseline in the n-back tasks revealed significant main effects of trial type (correct rejection, correct response) and visual complexity (low, high). The analyses of the pupil size deviation from the baseline measures in the reference-back tasks revealed statistically significant main effect of trial type (reference, comparison (correct rejection), and correct response) and interaction effects of visual complexity (low, high) and trial type as well as task (r1, r2) and trial type.

Changes in pupillary baseline measures (so called 'tonic' changes) are believed to be influenced by general factors, such as anxiety, stress or level of physiological arousal (Kahneman, 1973, Karatekin et al., 2003). Generally, larger tonic pupillary sizes are associated with wakefulness and activation (Van Der Meer et al., 2010) and were found to reflect higher working memory capacity (Heitz et al., 2008; Van Der Meer et al., 2010) in comparison to smaller pupil sizes that are more associated with fatigue and drowsiness (e.g., Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010; Morad, Lemberg, Yofe, & Dagan, 2000). In the current experimental work, the results of the pupillary baseline measures (Figure 12) and the measures that were obtained during the active thinking task, in which participants were asked to think either about a worrisome topic or a leisure activity, showed smaller pupillary sizes in the 'worry' condition than in the 'no worry' condition.

Overall, the pupillary baseline measures peaked in the n2 task possibly showing a shift to higher task engagement. The difference between the baseline measures in the 'worry' and 'no worry' conditions is smaller in the n2 tasks than in the n1 tasks. Considering the reference-back tasks, the difference in the baseline measures between the 'worry' and 'no

worry' conditions is smaller in the r2 task than in the r1 task. The same patterns are observed in the results of the RS and binary choice data mainly relating relatively smaller baseline pupillary sizes to lower performance data.

Pupillary deviation from the baseline measures during task performance that are evoked by task demands (so called 'phasic' changes) are believed to reflect cognitive effort (Beatty, 1982; Kahneman, 1973, Karatekin et al., 2003). In the present experiment, higher measures of the pupil size deviation from the baseline were observed in the 'worry' condition as compared to the 'no worry' condition (Figures 9, 10, 11, C1, Appendix C); however, the statistical analyses did not show a main significant effect of condition or significant interaction terms that included condition in the analyses of the mean pupil size deviation from the baseline measures. As the case may be, several processes and factors might be contributing to the pupillary changes in the present experimental work and therefore the average measures over the entire trial time that were used in the statistical analyses in the current experiment may have purged possible effects related specifically to worry. A different and more sensitive approach analyzing the temporal unfolding of the pupil signal (Wierda, van Rijn, Taatgen, & Martens, 2012) may have given more accurate results and be more adequate to employ for the purposes of the current experimental work. As visual examination of the morphology of the pupil dilation curves in each type of trial reveals (Figure C1, Appendix C), separate patterns and influences are seen during different trial time intervals. It is likely that the analysis of temporal unfolding of the pupil signal would reveal more information regarding the effects and interaction terms that include the 'worry' and 'no worry' conditions (Wierda, van Rijn, Taatgen, & Martens, 2012). However, the temporal unfolding analysis of the pupillary data was outside the scope of the current thesis work.

Results of the pupil size deviation from the baseline in a fairly similar study conducted by Clarke and Johnstone (2013), that investigated the effects of state anxiety on

performance of the n-back tasks, showed that increased difficulty in the n-back tasks resulted in a greater cognitive effort in an induced 'threat' condition than in a 'no threat' condition indicated by higher pupil size deviation from the baseline. As visual examination of the pupil size deviation from the baseline in the n-back tasks in the current experiment reveals (Figure 9), similar, although not significant, patterns with greater differences in pupillary deviation from the baseline between the 'worry' and 'no worry' conditions in the n2 task than in the n1 task were obtained. These differences may suggest that more cognitive effort was employed when carrying out the n2 task in the 'worry' condition than in the 'no worry' condition and this higher task engagement could have possibly contributed in relieving the disadvantage in the RS and accuracy measures in the 'worry' condition during the n2 task as compared to the n1 task. The same pattern was seen in the r1 task also resulting in lesser difference in performance between the 'worry' and 'no worry' conditions.

On the other hand, mean pupil size deviation from the baseline patterns between the tasks in the current experiment may also be related to the task difficulty level. An increase in pupil size due to task demands was found to be most expressed in moderate difficulty tasks, not well apparent in easier tasks that are considerably below resource limits and generally decreasing in too difficult tasks in cases where task demands exceed available resources (Granholm, Asarnow, Sarkin, & Dykes, 1996). Smaller differences between the conditions in the n1 and r2 tasks may be related to lower demands that were put by these tasks. As the results of the binary choice data reflect (Figure 6), the proportion of correct answers was relatively high in the n1 and r2 tasks as compared to n2 and r1 tasks indicating that these tasks were not too demanding. This may be one of possible reasons why the results of mean pupil size deviation from the baseline did not reveal statistically significant interaction effect of the condition ('worry', 'no worry') and increased task difficulty that was found by Clarke and Johnstone (2013) using more difficult n-back tasks (2-back and 3-back).

In general, the pattern showing decreased pupil size baseline measures and increased pupil size deviation from the baseline measures that emerged in the ‘worry’ condition in the current experimental work can be linked with an exploitative behavioural profile (Gilzenrat et al., 2010). This behavioural profile encompasses narrower focus, exploitation of familiar behavioural patterns as well as avoiding exploration outside a current task (Jonathan, Samuel, & Angela, 2007). Exploitative state of mind may be associated with better task performance caused by narrower focus; however, it is also associated with drowsiness and other low-arousal states (e.g., Gilzenrat et al., 2010). Concerning the current experiment, this behavioural profile could possibly be related to narrower focus on internal phenomena, such as worrisome thoughts rather than the current task and therefore not resulting in improved performance in all the tasks. However, with increased deviation from the baseline measures the task performance seemed to improve in the ‘worry’ condition as well. In contrast to the exploitative behavioural profile, larger pupillary baseline measures and smaller deviation from the baseline measures as obtained in the ‘no worry’ condition in the current experiment has been linked with an explorative behavioural profile involving willingness to take risks and search for alternative behaviours (Jonathan, Samuel, & Angela, 2007; Gary Aston-Jones, & Cohen, 2005).

Regarding the role of the maintenance function and the involvement of the central executive updating function during the ‘worry’ and ‘no worry’ conditions, visual examination of the mean pupil size deviation from the baseline data for each trial type requiring different set of cognitive functions in the n-back and reference-back tasks (Figure C1, Appendix C) indicates that there may be possible differences. However, the statistical analyses of the pupil dilation data averaged over whole trial epoch did not reveal significant results and, as mentioned before, a different and more sensitive approach is needed to employ for further examination. Concerning the possible role of the visual complexity of stimuli, it is difficult to

estimate how the visual stimuli themselves actually affected the pupil dilation data even if the overall luminance was controlled for. There was variability within the stimuli that may have mostly differed over the two levels of visual complexity; therefore, no direct conclusions regarding the differences in cognitive effort required to process stimuli of lower and higher visual complexity can be drawn from the pupillary data obtained in the current experiment.

In general, mean pupillary baseline measures and mean pupil size deviation from the baseline measures indicate differences between the ‘worry’ and ‘no worry’ conditions. However, it is not clear, if the baseline measures reflect exactly induced worry or if the thought generation task in the ‘no worry’ condition asking participants to think about an activity that they enjoy doing was causing relatively larger pupillary baseline sizes. Yet, the baseline patterns combined with the mean pupil size deviation from the baseline patterns, and the RS data showing results that are in line with previous studies using different anxiety inducing paradigms (e.g., Clarke & Johnstone, 2013; Vytal, Cornwell, Arkin, & Grillon, 2012), provide a more reliable support that the worry induction paradigm used in this experimental work had an intended effect.

Conclusion

The results of the current experimental work showed a greater disadvantage in the RS and the proportion of correct responses in an induced ‘worry’ condition than in the ‘no worry’ condition during easier n-back task than during more difficult n-back task. This dynamic indicates that higher task engagement may possibly shield from the detrimental effects of worry on task performance. In addition, the use of the combination of the comparable n-back and reference-back paradigms in the current experimental work indicated that maintenance function might be mainly responsible for the alleviating effects of increased task difficulty in the n-back tasks during worry.

Moreover, the present experimental work revealed that visual complexity of stimuli has an important role when investigating the relations between worry and different cognitive processes. The findings of the present experiment show greater interference of more complex visual information during the task performance in the 'worry' condition than in the 'no worry' condition.

Pupil baseline data obtained in the current experiment indicated differences between the 'worry' and 'no worry' conditions showing higher baseline pupil sizes in the 'no worry' condition associated with, among others, higher working memory capacity (Heitz et al., 2008) as compared to smaller pupil sizes in the 'worry' condition. Visual examination of the pupillary data also revealed patterns associated with narrower focus and exploitation of familiar behaviours in the 'worry' condition and patterns associated with explorative state of mind, encompassing greater willingness to take risks and search for alternative behaviours, in the 'no worry' condition.

Limitations, Future Directions and Practical Application

Due to limited time resources, the current experimental work used repeated measures design with two conditions ('worry' and 'no worry') in one experimental session. These two conditions may possibly have had carry over effects on one another. In addition, the 'no worry' condition cannot be considered 'neutral', and therefore no direct conclusions about the possible effects of the 'worry' condition can be drawn. The other major limitation of the current experiment is the utilization of an excessive number of unique combinations of condition ('worry', 'no worry'), task (n1,n2,r1,r2) and visual complexity level (low, high). This large number of conditions did put constraints on the statistical analyses.

Furthermore, the current experiment used two levels of difficulty in the n-back tasks, 1-back and 2-back. However, some previous studies indicate that the 3-back tasks may be a threshold for shielding from negative effects of worry and anxiety (e.g., Vytal et al., 2012;

Clarke & Johnstone, 2013); therefore, using more difficult n-back tasks could have possibly revealed clearer effects.

Regarding the analyses of the pupil dilation data, including only the average changes over the full length of trial might not been a method sensitive enough to capture possible effects. A more advanced analysis of the full temporal profiles might be needed. However, this was outside the scope of the present thesis work.

Notwithstanding the limitations, the results of the current experiment revealed findings that can build grounds for future research. The novel finding considering the interaction of visual complexity of stimuli and increased difficulty in tasks during the ‘worry’ and ‘no worry’ conditions could encourage future researchers to consider visual qualities of stimuli when designing experiments investigating effects of worry and anxiety on different cognitive functions. Moreover, this finding could inspire more research concerning the shift of allocation of attentional resources from willful and planned attentional guidance to increased processing and interference of perceptual information caused by a change in person’s internal state. By investigating the level of distraction caused by visual information during worry and distress, the research in this direction could have practical application not only in the fields of anxiety, but also, among others, driving and piloting.

Furthermore, more research is needed to investigate what more precise cognitive functions may be prone to the negative effects of worry and what functions, by higher task engagement, can alleviate these effects. The current research did investigate the updating and maintenance functions by using the combination of the n-back and reference-back paradigms; however, the executive inhibition function was not separated from the other functions in these tasks and was always involved during the correct rejection trials. More research concretely separating and investigating the interactions of worry and different sub-functions of the central executive as well as mental object maintenance is eminently needed. Furthermore, it

is not clear if longer periods of higher task engagement would still alleviate the deteriorative effects of worry and anxiety on task performance or if, after a certain amount of time, anxiety and worry would start to interrupt with the task performance possibly because of higher fatigue in anxious individuals. In this respect, more research including different difficulty levels of tasks and investigating different periods of task engagement is needed.

More knowledge about the easing effects of engagement of different cognitive functions during worry and anxiety and information about the period of this engagement during which the best results are obtained could be beneficial in development of different cognitive behavioral therapy techniques as well as in designing computer applications and games that could possibly help to alleviate feelings anxiety and interference of worry.

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Appendix A

Comparison of the N-back and Reference-back Paradigms

A comparison of cognitive functions required to carry out tasks within the n-back and reference-back paradigms is presented in Table A1, overleaf.

Table A1.

Comparison of n-back and reference-back paradigms. Prepared according to Ecker, Lewandowsky, Oberauer and Chee (2010) and Rac-Lubashevsky and Kessler (2016).

Function	Description	N-back	Reference-back	Conclusion
Updating	Encoding new items to working memory	All the trials	Reference trials	Controlled and can be manipulated separately from other functions in the reference-back tasks
	Binding new items to their position within the set of items held in working memory	All the trials	Not required	Binding the new item to its position is required only in the n-back tasks
	Removing outdated information from positions that are no-longer relevant (items that appeared more than n trials ago)	Relevant trials from n-one to n-two	Reference trials	Removing no longer relevant items is required in the both tasks. In the reference-back task this function is required during the reference trials
Matching	Comparing the new item to the one that appeared n trials before	Matching should always refer to the stimulus that appeared n-trials before	Matching should refer to the most recent reference trial	Operation is the same in the both tasks
Inhibition	Inhibiting irrelevant distraction during the comparison process (including both internal and external distractors)	All irrelevant trials	All irrelevant trials	Operation is the same in the both tasks
Maintenance	Holding information in a stable manner, impenetrable to irrelevant distraction from the environment	Time span from n-one to n-two	Time span between reference and match	Controlled and can be manipulated in the reference-back tasks to a greater extent and in isolation from updating functions

Appendix B

Descriptive Statistics of the Binary Choice and RS Data

Mean reaction speed scores, standard deviation and the number of trials for each task, condition and visual complexity level are presented in Table B1 below.

Table B1

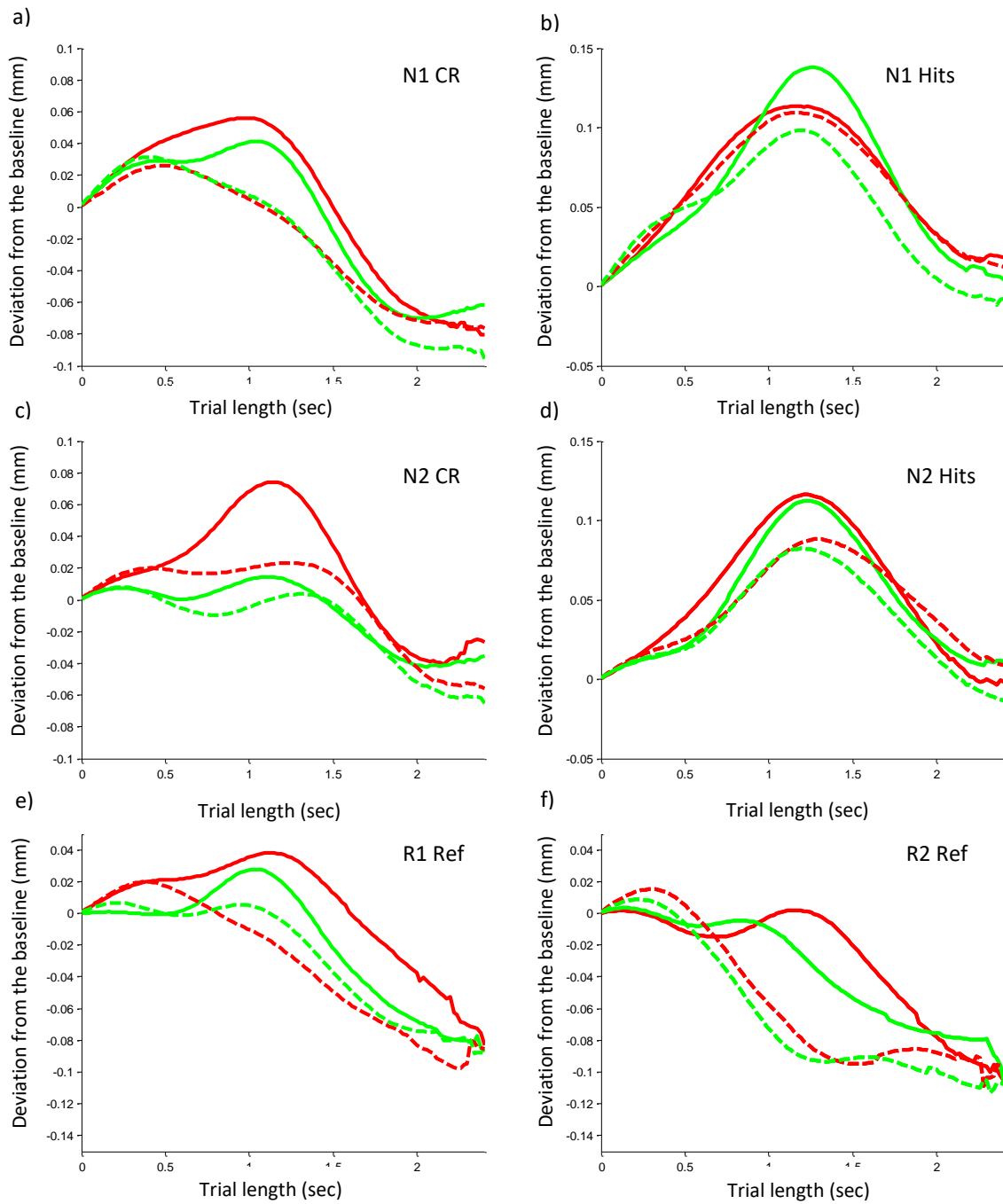
Mean reaction speed scores, standard deviation and the number of trials for each task, condition and visual complexity level.

		N1			N2			R1			R2		
		<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>
No worry	Low complexity	331	1.63	0.53	278	1.28	0.51	191	1.50	0.52	127	1.48	0.53
	High complexity	350	1.61	0.49	293	1.29	0.50	212	1.53	0.54	138	1.37	0.49
Worry	Low complexity	332	1.61	0.53	311	1.31	0.49	196	1.54	0.50	146	1.44	0.49
	High complexity	335	1.51	0.48	299	1.26	0.44	169	1.48	0.48	124	1.48	0.38

Appendix C

Pupil Size Mean Deviation from the Baseline during Each Trial Type

Figure C1 below shows mean pupil size deviation from the baseline for each trial type in the reference-back and n-back tasks.



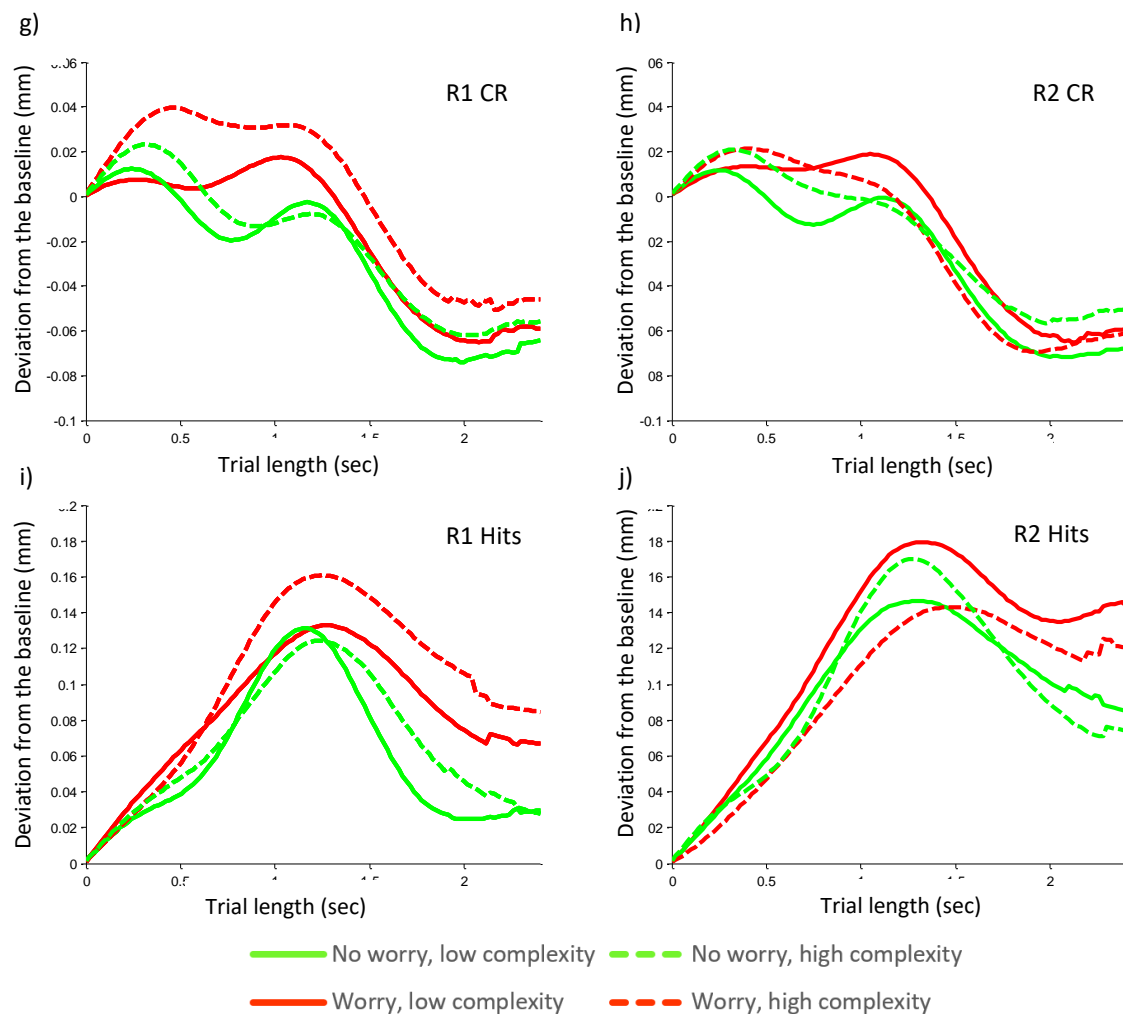


Figure C1. Mean pupil size deviation from the baseline (in millimetres) averaged over all participants during different types of trials in n1, n2, r1 and r2 tasks: a) correct rejection trials (CR) in n1 task; b) correct response trials (Hits) in n1 task; c) correct rejection trials (CR) in n2 task, d) correct response trials (Hits) in n2 task; e) reference trials (Ref) in r1 task; f) reference trials (Ref) in r2 task; g) correct rejection trials (CR) in r1 task; h) correct rejection trials (CR) in n2 task; i) correct response trials (Hits) in r1 task; j) correct response trials (Hits) in r2 task.