博士論文

Dysregulation of attention control mechanisms of working memory in high-anxiety individuals

（高不安者におけるワーキングメモリ注意制御機構の調節異常）

星野　貴俊

To Prof. Yoshihiko Tanno, my supervisor,

who led me here to complete the work.

To my cheerful partner, dog and cat, healing me everyday.

To my parents, for the incredible patience.

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Abstract

There is substantial evidence that dispositional individual variation in anxiety (trait anxiety) is associated with impaired executive control of attention. While several studies have shown relatively greater interference effects from distractor/competitor stimuli during visual-perceptual processing in high anxiety individuals, it is largely unknown whether anxiety has an impact upon executive control during interference/competition resolution among mental representations in WM under the absence of current perceptual inputs. Since high trait-anxious individuals often exhibit difficulty controlling maladaptive anxious apprehension or worry, an anxiety-provoking thought process that often arises in the absence of external triggering stimuli (e.g., Hirsch & Mathews, 2012), researches into the negative impact of anxiety on cognitive control process acting on mental representations in WM has clinical relevance and significance. Here, I would focus on ‘interference/competition resolution (chapter 2)’, ‘distractor resistance (chapter 3)’, and ‘intrusion resistance (chapter 4)’ which are the cognitive control responsible for selectively accessing or maintaining task-relevant mental representation(s) within WM in the face of competition/interference from various sources of distractors.

The results in chapter 2 demonstrated that there are larger interference effects from a salient or active distractor held in WM for high trait-anxious individuals who are

engaged in either reflective processing (refreshing another word) or perceptual processing (reading a new word), at least when the distractor word is semantically related to the target. In addition, this study showed weaker distractor resistance in high-anxious individuals using the complex span paradigm, called the continuous processing span task.

Moreover, measuring the brain activity by NIRS, this study demonstrated that high-anxious individuals consistently exhibited greater activations across left lateral PFC under high WM load. By contrast, they showed weaker activation only in inferior part of IFG under low WM load. This pattern of results suggests that activities in subregions of left lateral PFC are differentially modulated by trait anxiety in conjunction with WM load (or available attentional resources).

These patterns of brain activation were interpreted within the framework of the attentional control theory and neurocognitive model of anxiety proposed by Bishop (2009). Executive control regions in left lateral PFC may be modulated by the level of trait anxiety in conjunction with task demand.

Chapter 1

Background

Introduction

Feelings of tension, unwanted worried thoughts, and unpleasant physiological symptoms such as palpitation or sweating are the primary components of anxiety. Anxiety affects almost everyone from time to time, and thus it is generally regarded as a part of basic emotions of humans. Also, anxiety is thought to have associations with an adaptive function serving to foster a state of vigilance and facilitate detection of danger in the environment, which helps the person respond quickly and effectively to threatening situations (e.g., Öhman & Mineka, 2001). However, excessive and pervasive anxiety is unbearably painful, puts emotional burden on the person, and thus can be pathological and highly disruptive of everyday life. Epidemiological study shows that life time prevalence of anxiety disorders is estimated to be around 29% in the United States (Kessler & Zhao, 1999). Moreover, research suggests that anxiety disorder may precede and even increase the risk for developing comorbid depression and substance abuse (Barlow, Sauer-Zavala, Carl, Bullis & Ellard, 2014). Consequently, there are great interests in advancing our understanding of the mechanisms underlying anxiety, leading to the development of effective approaches for treating maladaptive aspects of anxiety.

Anxiety and cognitive dysfunction

Anxiety is not only a problem of emotion; it also affects an individual's cognitive functioning. Here, this thesis focuses exclusively on the personality trait which represents the dispositional individual variation in experiencing anxiety or trait anxiety. High levels of trait anxiety and its related personality traits such as neuroticism are well-established vulnerability for pathological anxiety and can even be risk factors for comorbid depression (Lahey, 2009; Kotov et al., 2010; Blackford & Pine, 2012). This highlights the importance of understanding the neurocognitive underpinnings of trait anxiety.

It is well documented that high trait-anxious individuals have difficulties controlling the processing of threat-related information (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). Anxious individuals frequently allow threat-related information to unduly affect their thoughts and actions. In particular, there are large body of evidence showing that anxious individuals have enhanced tendency to preferentially allocate attention toward threat-related information when they are present in the immediate environment, even when this comes at the expense of task-goals and ongoing behavior (Bar-Haim et al., 2007; Cisler & Koster, 2010). Biased processing accounts of anxiety propose that this attentional bias to threat relative to neutral or non-threatening ones (i.e., preferential processing of threatening information) plays a central role in the etiology and maintenance of pathological anxiety (Beck & Clark, 1997; Mathews & Mackintosh, 1998; Williams, Watts, MacLeod, & Mathews, 1997; MacLeod & Mathews, 2012). This view of anxiety indicates that individual differences in trait anxiety reflect the difference between high and low trait-anxious individuals' sensitivity to potentially threatening information around them, rather than the difference in cognitive capability overall.

In contrast, neurocognitive theories of anxiety place alterations or impairments in general cognitive processes such as attention and working memory at the center of the characteristics in high trait-anxious individuals (Berggren & Derakshan, 2013; Bishop, 2007, 2008; Eysenck et al., 2007; Eysenck & Derakshan, 2011). It has been demonstrated that individuals with high levels of trait anxiety show impairments, compared to those low in trait anxiety, in performing cognitive tasks that lack any explicit threat-related information. For example, there is evidence that trait anxiety interferes with short-term memory maintenance (Derakshan & Eysenck, 1998; Richards, French, Keogh, & Carter, 2000; Tohill & Holyoak, 2000) and attention control (Pacheco-Unguetti et al., 2010), as well as higher-order complex cognitive operations such as reasoning (e.g., Darke, 1988; Derakshan & Eysenck, 1998;) and sentence comprehension (Calvo, Ramos, & Estevez, 1992), although threatening or anxiety-provoking information are totally absent. A wealth of evidence shows that anxiety has consistent associations with increased distractibility (Derryberry & Reed, 2002; Eysenck, 1992; Cisler & Koster, 2010 for a review) and poor executive control of attention (Ansari & Derakshan, 2010; Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009; Pacheco-Unguetti, Acosta, Callejas & Lupiáñez, 2010). These findings suggest that trait anxiety can generally modulate neurocognitive processes of controlled or top-down mechanisms even when the stimuli themselves are not threatening.

One prominent neurocognitive account of anxiety is the attentional control theory proposed by Eysenck and colleagues (ACT; Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007). According to the ACT, anxiety impairs cognitive operations through its disruptive effect on the top-down regulatory system and enhancement of bottom-up attentional system (e.g., Corbetta & Shulman, 2002), which are assumed to complementary subserve the controlling of working memory (i.e., central executive; Baddeley, 2007; Cowan, 1992; Oberauer, 2002). Regarding the impairment in top-down or executive control in relation to anxiety, for example, high trait-anxious individuals exhibit difficulty responding to a target arrow flanked with perceptually competing distractor arrows relative to those low in trait anxiety (Pacheco-Unguetti et al., 2010). Similarly, high trait anxiety individuals have been shown difficulty performing anti-saccade tasks, in which participants are required to execute a saccade (horizontal eye movement) toward a target stimulus located in the opposite direction of a perceptually salient flashed stimulus (e.g., Derakshan, Ansari, Shoker, Hansard, & Eysenck, 2009). Parallel results concerning the inefficiency of executive control in high trait-anxiety individuals are also obtained in psychophysiological studies (Ansari & Derakshan, 2011; Basten, Stelzel, & Fiebach, 2011; Osinsky, Alecander, Gebhardt, & Henning., 2010). In neuroimaging study, Bishop (2009) reported that high-anxious individuals measured by trait anxiety exhibited reduced activation of dorsolateral prefrontal cortex (DLPFC) during a visual search task introducing perceptual conflict, despite completely absence of threat-related stimuli. DLPFC is commonly thought to be a central part of brain network responsible for flexible control of attention (e.g., Hopfinger, Buonocore & Mangun, 2000; Westerhausen, Moosmann, Alho, Belsby, Hämäläinen et al., 2010; see Corbetta & Shulman, 2002; Duncan & Owen, 2000, for reviews). Therefore, high levels of trait anxiety can interfere with the neural substrates of the attentional control mechanisms in cognitively challenging situations in which distracting or irrelevant information is competing with the target stimulus.

Anxiety and cognitive control over mental representation

Compared to the richness of studies investigating the negative impact of anxiety on cognitive control in visual/perceptual processing, researches investigating the impact of anxiety in cognitive operations acting on mental or memory representations are comparatively scarce. Importantly, recent studies demonstrated that the ability to deploy attentional resources from an arousing aspect of representation within working memory is essential for emotion regulation (Levens & Gotlib, 2010; Thiruchselvam, Hajcak, & Gross, 2012). In response to these findings, some cognitive controls on representations within working memory (e.g., filtering out the irrelevant item) has recently been highlighted in relation to neurocognitive underpinnings of emotion regulation in anxiety (Basten et al., 2012; Stout, Shackman, & Larson, 2013; Qi, Ding, &Li., 2014). Working memory (WM) refers to a limited-capacity system enabling a small amount of mental representations to be active and easily accessible state for a brief period of time for ongoing cognition (Baddeley, 2012). Therefore, content of WM is supposed to be a basis of current thoughts and actions (Johnson, 1983). Since high trait-anxious individuals often exhibit difficulty controlling maladaptive anxious apprehension or worry, an anxiety-provoking thought process that often arises in the absence of external triggering stimuli (e.g., Hirsch & Mathews, 2012), researches into the negative impact of anxiety on cognitive control process acting on mental representations in WM has clinical relevance and significance (Basten et al., 2012; Stout, Shackman, & Larson, 2013).

Thus far, some evidences indicating the close relation between trait anxiety and difficulties controlling representations in WM have come mainly from electroencephalographic (EEG) study. For example, Stout et al (2013) demonstrated that high trait-anxious individuals have difficulty filtering the threat-related distractors (e.g., fearful faces) out of WM. They measured the contralateral delay activity, the robust event-related potentials during the maintenance of visual WM (e.g., Vogel & Machizawa., 2004). Moreover, Qi et al (2014) showed that difficulty filtering task-irrelevant distractors out of WM in individuals with high levels of trait anxiety is not limited to threat-related information but can be generalized to emotionally neutral stimuli (e.g., colored rectangles in red or green). This pattern of results is confirmed recently by the same research group (Stout, Shackman, Jonson, & Larson., 2014). These findings consistently indicate that there can be difficulties inhibiting task-irrelevant information unnecessarily gaining entry to WM in high trait-anxious individuals.

Cognitive control focused in the present study

When considering the association between trait anxiety and (impaired) cognitive control on mental representations in WM, there must be need for distinction from visual/perceptual (i.e., external) processing. As mentioned earlier, the neurocognitive theory of anxiety, the ACT (Eysenck et al., 2007) , proposes that trait anxiety disrupts the functions of the central executive, which is the top-down regulatory system of WM executing the inhibitory control and attentional set shifting. Of these, inhibitory control involves at least three subtypes: prepotent response inhibition, distractor resistance, and intrusion resistance (Friedman & Miyake, 2004). The typical form of the prepotent response inhibition can be seen in the response conflict paradigms such as the Stroop task (Stroop, 1932) and the go/no-go task (Rosvold, Mirsky, Bransome, & Beck., 1956), and it is also called behavioral inhibition (Nigg, 2000). This sort of inhibitory control mainly targets bottom-up/stimulus-driven responses triggered by a stimulus that is visually or perceptually presented in front of a person performing the task. By contrast, latter two forms of inhibitory control are implicated also in memory process, particularly in the protection of capacity-limited WM storage against multiple sources of interference (MacLeod, Dodd, Sherd, Wilson, & Bib, 2003; Nigg, 2000; Smith, 1992). The mental representation of task sets and goals in WM plays a critical role in exerting adaptive behaviors; sustaining goal-directed attention and selection of information processed (e.g., memory encoding, retrieval, or thought) in the face of competition with potential sources of distraction or interference (Miller & Cohen, 2001; Postle, 2006). Therefore, how anxiety affects the inhibitory control implicated in WM needs to be investigated in order to clarify the neurocognitive mechanisms of the maladaptive cognition in individuals with high levels of trait anxiety.

Here, this thesis will use the term ‘interference/competition resolution (chapter 2)’, ‘distractor resistance (chapter 3)’, and ‘intrusion resistance (chapter 4)’ to describe the cognitive control responsible for selectively accessing or maintaining task-relevant mental representation(s) within WM in the face of competition/interference from various sources of distractors. Although, the term inhibition should be more popular in this field, it seems not appropriate in the present researches because this term implies that down-regulation (attenuation) of competing information is presupposed to be necessary for making the goal-directed responses (e.g., Nee, Jonides, & Berman., 2007). However, there is little empirical evidence supporting for inhibitory process acting at a cognitive level (see MacLeod et al., 2003 for a review).

Neural basis of interference control in working memory

Given the severity of limitation in WM capacity (4±1 items held in at a time; Cowan, 1992; 2002), the ability to avoid the disruptive effect (i.e., interference) from task-irrelevant information is vital for the successful functioning of WM (Engle et al., 2001; Freedman & Miyake., 2004; Kane et al., 1999; Nee et al., 2007). Although, how to describe and organize the executive processes of WM is the issue being under debate, recent advances in cognitive neuroscience suggest that the functions required for interference control/resolution have mostly been assigned to the lateral prefrontal cortex (PFC; Courtney et al., 2004).

Nee et al (2012) organize the executive functions subscribed to WM in terms of the processes that is assumed to act on representation(s) held in WM, identifying the four putative ‘memory-related’ functions (shifting, updating, interference control, and refreshing). Of these functions, interference control and refreshing are the members of the cognitive control subserved in the lateral PFC (also the locus of the disruptive effect in anxiety; Bishop, 2007; 2009). They further subdivided interference control into distractor resistance and intrusion resistance based on the classification of Freedman and Miyake (2004). In addition to interference control, they also included refreshing, which is the minimal executive process in WM foregrounding the just-activated representation among others (Johnson, 1983). This minimal operation is well known contributor of the memory maintenance, and includes the process of competition resolution when selecting a particular representation among others that are interconnected mutually (Higgins & Johnson., 2009). In their literature review, Bledowski, Kaiser, and Rahm (2010) also refers to the refreshing in terms of the coping for ‘inter-item interference’ within WM. Considering that trait anxiety can negatively affects the executive control mechanism(s) located in the lateral PFC necessary for interference/competition resolution (Bishop, 2009 ; Eysenck el al., 2007), there could be anxiety-related dysfunction in the process of interference resolution among internal/mental representations implemented in the lateral PFC. By investigating into the association of anxiety with WM functions, I expect to get the core problem of anxiety-related difficulties in controlling anxious apprehension (i.e., worry) and prevention of unwanted intrusive thought.

In summary, this research program aimed at the demonstration of disruptive effect(s) of trait anxiety on cognitive control acting as the selection (refreshing) and the protection (distractor resistance and intrusion resistance) of relevant representation in WM.

Chapter 2

Introduction

There is substantial evidence that dispositional individual variation in anxiety (trait anxiety) is associated with impaired executive control of attention (see Berggren & Derakshan, 2013 for a review). For example, high trait-anxiety individuals exhibit difficulty responding to a target arrow flanked with perceptually competing distractor arrows relative to those low in trait anxiety (Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010). Similarly, high trait anxiety individuals have been shown difficulty performing antisaccade tasks, in which participants are required to execute a saccade (horizontal eye movement) toward a target stimulus located in the opposite direction of a perceptually salient flashed stimulus (e.g., Derakshan, Ansari, Shoker, Hansard, & Eysenck, 2009). Cognitive accounts of anxiety-related attentional impairment suggest that anxiety can enhance bottom-up or stimulus-driven attentional processing while impairing top-down or goal-directed regulation of attention, which can result in difficulties with interference resolution (e.g., Eysenck, Derakshan, Santos, & Calvo, 2007).

While several studies have shown relatively greater interference effects from distractor/competitor stimuli during visual-perceptual processing in high anxiety individuals, it is largely unknown whether anxiety has an impact upon executive control during interference/competition resolution among mental representations in working memory under the absence of current perceptual input. WM refers to a collection of processes or systems that enable the maintenance of information in an active state as well as the manipulation of such information during ongoing cognition (Baddeley & Logie, 1999). Information maintained in WM has been conceptualized as a hierarchical organization of particular representations, with some being activated within the focus of attention while others may be currently out of focus (Cowan, 1999). This notion raises the possibility that activated WM content could serve as an effective distractor with regards to a target that is also active within WM. If anxiety impairs the executive control of attention operating upon WM contents, in a fashion that parallels the effect observed in visual-perceptual attention, high anxiety individuals should exhibit a difficulty in resolving interference from a highly-activated distractor held in WM. I examined this question in light of the observation that high-anxiety individuals often exhibit difficulty controlling anxious apprehension or worry, an anxiety-provoking thought process that often arises in the absence of external triggering stimuli (e.g., Hirsch & Mathews, 2012), which implies that anxiety could impair the control process involved in performing operations on mental representations. Hence, it is of great importance to make a distinction between processing of external/perceptual stimuli and performing cognitive operations upon internal/mental representations.

According to the Multiple-entry, Modular memory framework (MEM; Johnson & Hirst, 1993), cognition can be classified into perceptual and reflective processes depending on the type of information processed. Perceptual processes work in response to external stimuli. In contrast, reflective processes operate upon internal mental representations such as thoughts and memories, independent of current external inputs (see also Chun, Golomb, & Turk-Browne, 2011). The MEM assumes that executive functions can be decomposed into simpler, more elementary component processes of reflection, such as refreshing (thinking back of a just-activated, easily accessible representation), rehearsing (vocally or subvocally cycling multiple, phonologically-coded representations to maintain them for longer period of time, Baddeley & Logie, 1999), reactivating (reviving currently inactive representations in a relatively automatic way), and retrieving (reviving currently inactive representations in a strategic or controlled fashion). These basic reflective processes are assumed to be the component processes that are recruited during higher-order cognitive functions such as thinking, problem solving, and decision-making (e.g., Johnson & Hirst, 1993). Refreshing can perhaps be regarded as the simplest or most minimal reflection component process, in that it involves the process of selecting a particular mental representation from among a set of others and focusing attention upon the target in the absence of an external stimulus (Raye, Johnson, Mitchell, Greene, & Johnson, 2007). Previous studies have shown that response times (RTs) for refreshing a just-seen word are significantly longer than RTs for reading a word presented visually, implying that merely accessing a just-seen word held in WM is more time-consuming or demanding of control processes than is perceptual processing such as reading an externally presented word (e.g., Raye, Mitchell, Reeder, Greene, & Johnson, 2008). Additionally, Higgins and Johnson (2009) showed that refreshing a particular word in a semantically related list could interfere with a subsequent attempt to refresh another word in the same list, which they call refresh-induced inaccessibility. Regarding the interference effects seen in refresh-induced inaccessibility, they suggest that enhanced activation of a particular word via refreshing makes it a stronger distractor/competitor within a set of stimuli that are closely interconnected in semantic memory (e.g., Collins & Loftus, 1975).

The present study adopted the MEM-based classification of cognition for conceptually and operationally clarifying reflective processes. The well-established selective refreshing paradigm (Higgins & Johnson, 2009; Raye et al., 2007) was utilized in order to manipulate competition strength among verbal materials in semantic dimension necessary for refresh-induced inaccessibility. In the present study, participants high and low in trait anxiety were presented with three-word set. After a given word list disappeared from view, participants were required to either refresh one of the words signaled by a dot cue, or repeat (re-read) a word that re-appeared visually (task 1). During Task 2, participants were presented with the same set of words a second time, and then required to either refresh one of the nonselected items from Task 1 or read aloud a new word that was presented visually. Therefore, the accessibility of a Task 2 target was examined as a consequence of whether the Task 1 target was refreshed (reflectively processed) or read (perceptually processed) in this paradigm. Our primary objective was to examine whether trait anxiety would enhance the magnitude of refresh-induced inaccessibility, which could be considered a minimal form of difficulty in interference resolution among WM contents. Given that anxiety could impair executive control for interference resolution, it was predicted that, compared to low-anxiety individuals, high-anxiety individuals would have more difficulty resolving interference strengthened via a previously refreshed word currently in the focus of attention when attempting to refresh another word when competition in a semantic dimension is introduced. Under this condition, I also expected that high-anxiety individuals would have more difficulty resolving interference from a previously refreshed distractor upon subsequent perceptual processing (reading a visually presented word).

Method

Participants

Forty-two undergraduate students (age: 18-28 years, mean age = 19.8, 28 females and 14 males) participated in the experiment in return for compensation (about $10 US). All participants had normal or corrected-to-normal vision. On the basis of trait anxiety as measured by trait subscale scores on the State-Trait Anxiety Inventory (STAI; Shimizu & Imae, 1981; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), they were divided into two groups according to whether scores were above or below the median value (high trait-anxious (HTA) and low trait-anxious (LTA) groups).

Materials

Word stimuli were selected based on prototypicality rank positions (i.e., exemplars) in semantic categories (Akita, 1980; Ogawa, 1972), for composition of semantically related lists. Four exemplars were selected from each of 65 semantic categories for a total of 260 words, and including low-, medium-, and high-ranking words in a category (mean rank positions: Low = 7.2, medium = 4.6, high = 2.3). No category appeared twice during the testing session. Mean word frequencies (low-, medium-, and high-rankings = 121.7, 304.4, 328.1, respectively) and mean familiarity ratings (low-, medium-, and high-rankings = 5.2, 5.5, 5.6, respectively) were assessed using a Japanese lexical properties database (Amano & Kondo, 1999; 2000). Mean mora lengths were 3.9, 3.7, 3.6, for low-, medium-, and high-rankings respectively.

Candidate words for semantically unrelated lists were selected using the same procedure described above, and were counterbalanced by intermixing them across categories.

Mean word frequencies for low-, medium-, and high-rankings were 171.7, 198.4, and 281.9 respectively, and mean familiarity ratings were 5.1, 5.4, and 5.4 respectively. Mean mora lengths were 3.8, 3.8, and 3.5 respectively.

Experimental task

The selective refreshing task (Higgins & Johnson, 2009) was adopted for use in this study (see Figure 2.1). A trial of this paradigm consists of two task phases. In task 1, participants were presented with semantically related or unrelated three-word set that they were asked to read aloud, after which they were presented with and required to again read aloud target words that appeared on the prior list (*repeat*), or were required to think back of and say aloud a target word that previously appeared at a dot cue's location (*refresh*). In task 2, participants were presented with and asked to read aloud the same set of words that appeared in task 1, after which they were required to either refresh a target word signaled by a dot cue which were never the same as the targets in task 1 (*refresh*), or to read aloud a new word which was not included on a list (*read*). Participants were instructed to respond verbally, as quickly and accurately as possible. Target word RTs were recorded and served as indices of efficiency in controlling reflective attention (refresh) or perceptual processing (repeat in task 1 and read in task 2).

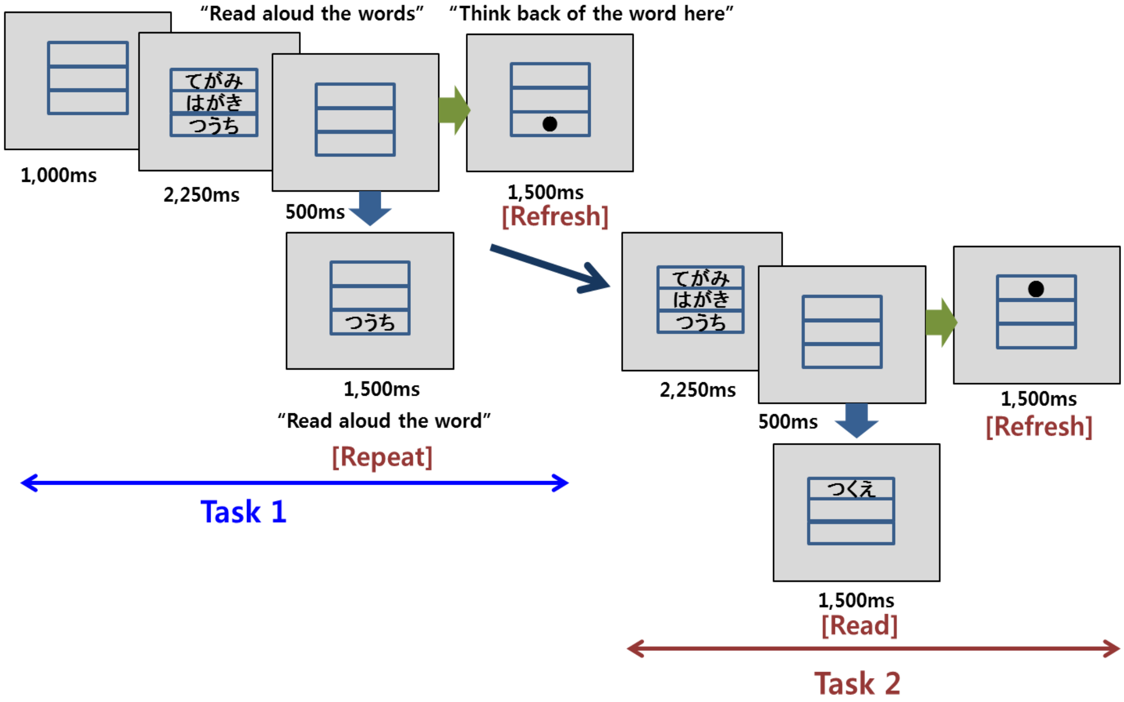

Figure 2.1 Task diagram of the selective refreshing task (Higgins & Johnson, 2009)
In Task 1, a three-word list is presented for 2,250 ms, followed by 500 ms delay.
Then participants are either asked to "Think back of the word here" (Refresh), or "Read aloud the word".
In Task 2, the same three-word list is presented again, followed by the similar 2 conditions;
Refresh or Read a word that does not appear in the list.

Each trial began with blank screen presented for 1,000 ms, followed by a three-word list arranged vertically (with each word inside a box) for 2,250 ms. Participants were asked to read the words aloud. Boxes remained on the screen throughout a trial. Following a 500 ms interval, either a dot cue or one of the three words was presented according to task condition (*refresh* or *repeat* conditions in task 1). In the task 1 *refresh* condition, a dot cue was presented for 1,500 ms in one of the three boxes previously occupied by a word. Participants were required to think of and say aloud the target word as signaled by the cue. In the task 1 *repeat* condition, one of the original three words was presented again for 1,500 ms at the same location as it previously appeared, and participants were required to read the target word aloud. After a 500 ms interval, the same three-word list was presented again on the screen for 2,250 ms. Participants were again asked to read the words aloud. Following a 500 ms interval, either a dot cue or a new word was presented according to task condition (*refresh* or *read* conditions in task 2). In the task 2 *refresh* condition, a dot cue was presented in one of the three boxes, and participants were required to think of and say aloud the target word as signaled by the cue. In the task 2 *read* condition, a new word was presented in one of the boxes and the participants were required to read the word aloud. A 3,000 ms interval separated each trial from the next. There were a total of 120 trials.

Half of the trials were *refresh* trials, with the remaining half consisting of *repeat* trials in task 1. The same was true for task 2, resulting in 4 experimental conditions in each list relatedness (*Refresh-Refresh*, *Refresh-Read*, *Repeat-Refresh*, and *Rpeat-Read*). The implementation orders for task condition and list relatedness were randomized, and prototypicality of target words was counterbalanced within participants in order to control for category typicality effects (Rosch, 1975). Word frequency and target word familiarity were also counterbalanced within participants, to control for their influences upon word recognition and reading (e.g., Hino & Lupker, 1998).

Neuropsychological working memory tasks

Reading span task (Daneman & Carpenter, 1980) and the letter-number sequencing task in Wechsler Adult Intelligence Scale third edition (WAIS-III; Wechsler, 1997) were administered for measuring general WM functioning. These tasks were carried out according to a common method except for the stop rules, such that all participants performed the same number of trials.

Apparatus

The experiment was conducted on a Dell Dimension 3100 computer with an Intel Pentium 4 central processor. The stimuli were presented on a 17-inch Sony CPD-E230 monitor, using E-prime software. Vocal responses were detected via an ELECOM MS-HS58V head-set and RTs were measured at vocal response onset via the voice key.

Procedure

Upon arrival at the laboratory, participants first completed the trait subscale of the STAI (STAI-T). After a five-minute rest, they filled out a questionnaire battery that included the state subscale of the STAI (STAI-S) and the Tension – Anxiety (TA), Depression – dejection (D) and Fatigue (F) subscales of the Profile of Mood States (PoMS; McNair, Lorr, & Droppleman, 1971; Yokoyama, 2005), which was used to assess temporary mood states.

Each participant performed the selective refreshing task after questionnaire completion. Before the test trials began, each participant performed three practice trials for each condition (Refresh-Refresh, Refresh-read, Repeat-Refresh, and Repeat-Read) using a randomly selected word set, to ensure comprehension of the task requirements. Participants were allowed to repeat the practice if they had any doubts about how to perform the task (although no participant did so). Participants filled out the same questionnaire battery (excluding the STAI-T) again upon completion of the 120 test trials. Participants were fully debriefed at the end of the session. Informed consent was obtained from each participant.

Results

Table 2.1 shows the summary statistics of the questionnaires and general WM capacity. On the basis of STAI-T scores, participants were divided into two groups via a median split: High trait-anxiety (HTA) and low trait-anxiety (LTA) groups. To validate this grouping procedure, an independent *t*-test of group was conducted with STAI-T scores as the dependent variable. As shown in Table 1, the HTA group had significantly higher STAI-T scores than the LTA group, $t(40) = 3.37$, $p = .002$, showing that these groups were reliably different from each other regarding trait anxiety. As Shimizu & Imae (1981) reported, scores of STAI-T were normally distributed in this study (see Appendix). HTA group scored slightly higher (but not statistically significant) and LTA group scored lower than the mean of undergraduates in Japan which is reported as 45.33.

Next, scores on mood measures taken before and after the experimental task were compared between groups. STAI-S scores taken before the task were only marginally different across the groups, $t(40) = 1.75$, $p = .087$, but no differences were found for STAI-S scores taken after the task or the other mood measures, *t*s < 1.12, *p*s > .134.

[Table 2.1 on the next page]

Table 2.1 Mean scores for trait anxiety and negative mood states in the High and Low Trait-Anxiety groups.

	Group			
	High Trait Anxious (n = 21)		Low Trait Anxious (n = 21)	
Measures	Pre-task	Post-task	Pre-task	Post-task
STAI-T	49.1 (8.2)	-	36.2 (8.7)	-
STAI-S	37.9 (9.3)	34.1 (7.7)	30.2 (7.4)	28.9 (8.4)
PoMS-TA	4.4 (1.6)	4.0 (1.4)	3.7 (2.1)	3.7 (2.5)
PoMS-D	4.8 (2.4)	4.5 (2.6)	4.9 (2.9)	4.2 (2.4)
PoMS-F	3.4 (1.7)	4.8 (2.6)	4.1 (2.2)	4.7 (2.8)
Reading span	5.3 (0.3)	-	5.3 (0.6)	-
Letter-number sequencing	19.7 (1.4)	-	19.5 (1.8)	-

Note. Standard deviations in parenthesis.

STAI-T = State-Trait Anxiety Inventory - Trait form

STAI-S = State-Trait Anxiety Inventory - State form

PoMS = Profile of Mood States

TA = Tension – Anxiety subscale in PoMS

D = Depression subscale in PoMS

F = Fatigue subscale in PoMS

Table 2.2 shows the mean RTs and standard deviations for the HTA and LTA groups on task 1. Each participant's mean RTs on each experimental condition were used as the representative values (i.e., the performance score). To test whether trait anxiety has an impact upon refreshing a just-seen word, RTs on task 1 were subjected to a 2 (group: HTA vs. LTA) × 2 (semantic relatedness: related vs. unrelated) × 2 (task 1 condition: *refresh* vs. *repeat*) mixed design analysis of variance (ANOVA) with relatedness and task 1 condition as within-subjects factors.

There was no main effect of group or interactions with group found for task 1 RTs, Fs < 2.51, ps > .12 , suggesting that both groups showed comparable performance in refreshing a just-seen word or repeating (re-reading) a visually presented word.

[Table 2.2 on the next page]

Next, I examined whether trait anxiety modulates the influence of a salient representation within WM (refreshed words during task 1) upon subsequent processing. Task 2 RTs re submitted into a 2 (group: HTA vs. LTA) × 2 (semantic relatedness: related vs. unrelated) × 2 (task 1 condition: *refresh* vs. *repeat*) × 2 (task 2 condition: *refresh* vs. *read*) mixed design ANOVA with relatedness, task 1, and task 2 conditions as within-subject factors. Each participant's representative values were the means of RTs

Table 2.2 Mean response times (msec) and standard deviations for the High and Low Trait-Anxiety groups on task 1.

task 1	Semantically related		Semantically unrelated	
	Refresh	Repeat	Refresh	Repeat
HTA	722 (78)	635 (46)	728 (82)	639 (56)
LTA	727 (69)	628 (51)	732 (77)	644 (63)

Note. Standard deviations in parenthesis.

within the experimental conditions. There was a significant main effect of task 1 condition, $F(1, 40) = 4.67$, $p = .037$, $\eta^2_p = .13$, in the form of longer task 2 latencies for previous (task 1) refreshing of words (710.6 ms) relative to previous reading (659.8 ms). The main effect of task 2 condition was also significant, $F(1, 40) = 6.34$, $p = .016$, $\eta^2_p = .22$, with longer latencies for refreshing a word (736.2 ms) relative to reading a new word (644.8 ms). Main effects of group, $F(1, 40) = 2.66$, $p = .110$, $\eta^2_p = .06$, and semantic relatedness, $F(1, 40) = .71$, $p = .404$, $\eta^2_p = .00$, did not reach significance.

Regarding the occurrence of refresh-induced inaccessibility, a significant two-way interaction of task 1 condition × task 2 condition was observed, $F(1, 40) = 7.78$, $p = .008$, $\eta^2_p = .19$. This interaction was qualified by a significant three-way interaction of semantic relatedness × task 1condition × task 2 condition, $F(1, 40) = 11.12$, $p = .002$, $\eta^2_p = .28$. A series of Bonferroni-corrected pairwise comparisons showed significantly longer latencies for the *Refresh-Refresh* condition compared with the *Repeat-Refresh* condition on the semantically related lists, $t(41) = 2.91$, $p = 0.023$, but not on the unrelated lists, $t(41) = 0.61$, *n.s.*, suggesting that the refresh-induced inaccessibility phenomenon was successfully introduced through competition along the semantic dimension. Additionally, significantly longer latencies were observed for the *Refresh-Read* condition compared with the *Repeat-Read* condition on the related lists, $t(41) = 2.62$, $p = 0.049$, but not on the unrelated lists, $t(41) = 0.22$, *n.s*. This pattern of results implies that refreshing operations can enhance the competitive influence of the selected word against non-selected ones in both reflective and perceptual processing. Relevant to our prediction, a four-way interaction was significant, $F(1, 40) = 13.84$, p = .0006, $\eta^2_p = .41$, indicating that the significant three-way interaction of semantic relatedness × task 1condition × task 2 condition was qualified by anxiety group (see Figures 1 and 2). A series of Bonferroni-corrected pairwise comparisons between the groups in each experimental condition were performed to test whether the negative impact of previously refreshed words on subsequent processing observed in the related list condition would vary as a function of trait anxiety. The HTA group showed significantly longer latencies compared with the LTA group for the *Refresh-Refresh* condition on the semantically related lists, $t(40) = 3.05$, $p = .032$, but not on the unrelated lists, $t(40) = 1.62$, $p = .83$. The HTA group also took marginally longer to respond in the *Refresh-Read* condition on the semantically related lists, $t(40) = 2.83$, $p = .057$, but not on the unrelated lists, $t(40) = 1.76$, $p = .67$. There were no group differences on RTs in either of the task 2 conditions that were preceded by task 1 repeat trials, *p*s > .68.

[Figure 2.2 & 2.3 on the following pages]

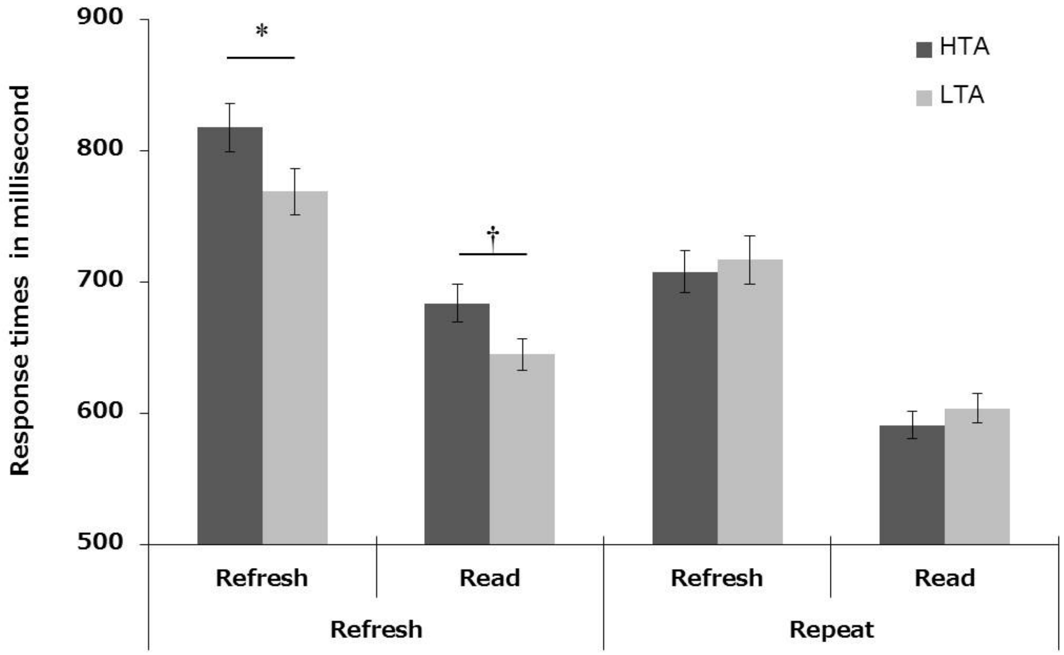

Figure 2.2 Mean response times (RTs in msec) for High Trait-Anxiety (HTA) and Low Trait-Anxiety (LTA) groups on task 2 in the semantically related lists.
Error bars denote standard errors of the mean.
Horizontal axis represents task conditions in task 1 (Refresh - Repeat) and task 2 (Refresh - Read).
* $p < 0.05$, † $p < 0.10$ (Bonferroni corrected)

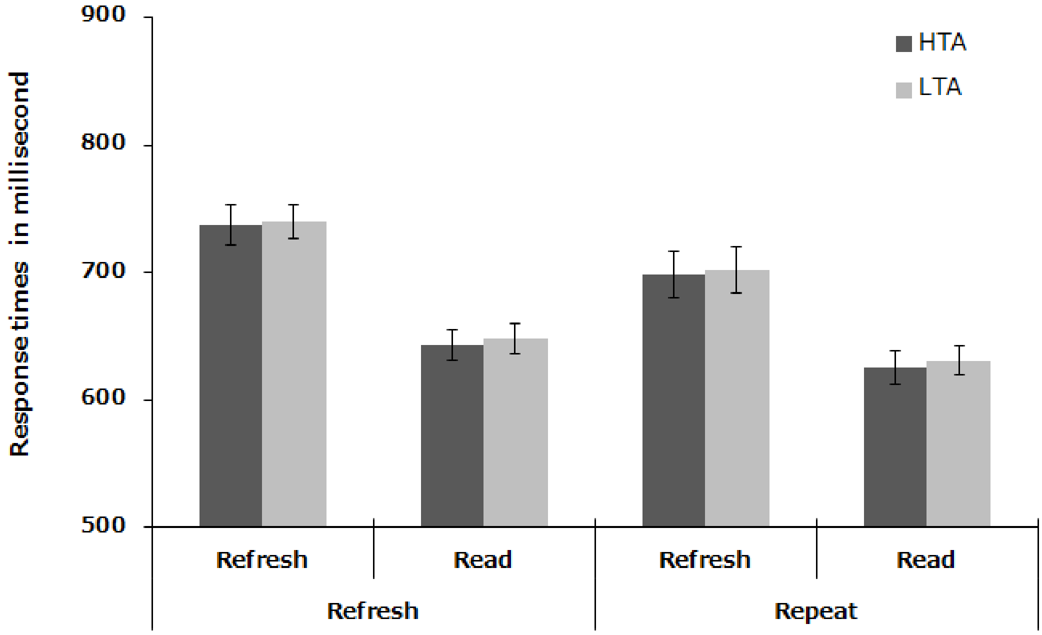

Figure 2.3 Mean response times (RTs in msec) for High Trait-Anxiety (HTA) and
Low Trait-Anxiety (LTA) groups on task 2 in the semantically unrelated lists.
Error bars denote standard errors of the mean.
Horizontal axis represents task conditions in task 1 (Refresh - Repeat) and task 2 (Refresh - Read).

Finally, correlational analyses were performed to examine the relationship between RTs for each task 2 condition and questionnaires (trait anxiety and mood measures). As expected, RT in Refresh-Refresh condition correlated significantly with the score of STAI-T ($r(40) = .38$, $p = .014$), suggesting that response latencies were longer as the levels of trait anxiety were higher. By contrast, no significant correlations were found on the other experimental conditions with STAI-T (rs < .11, p > .32).

As for the mood states, Depression – dejection PoMS subscale scores taken before the task showed a weak correlation with *Refresh-Read* condition RTs for unrelated lists, $r(40) = .29$, $p = .09$, implying that participants currently in depressive mood states took more time to respond to a new word in this condition. There were no significant correlations for other combinations of mood states and RTs, |rs| < .19, ps > .23.

Discussion

A selective refreshing task was used to investigate the impact of trait anxiety upon refreshing a word stimulus in WM, a basic reflective process, as well as the relationship between trait anxiety and the impact of refreshing on subsequent processing, namely refresh-induced inaccessibility (Higgins & Johnson, 2009). Consistent with the study of Higgins and Johnson (2009), I observed refresh-induced inaccessibility for semantically related word lists. More germane to our specific research question, the magnitude of this interference effect was modulated by trait anxiety level, such that the HTA group had more difficulty in refreshing a word from a semantically related list when another word from the list had been previously refreshed. Moreover, there was a similar (but marginal) tendency observed when participants had to read new words during task 2. I found no group differences on RTs for task 1, suggesting that both groups showed comparable performance in merely refreshing a single word in a list. Taken together, the present results demonstrated that there are larger interference effects from a salient or active distractor held in WM for high trait-anxious individuals who are engaged in either reflective processing (refreshing another word) or perceptual processing (reading a new word), at least when the distractor word is semantically related to the target.

In light of the explanation concerning the refresh-induced inaccessibility (Higgins & Johnson, 2009), our findings of relatively larger interference effects in highly-anxious individuals can be interpreted as a manifestation of anxiety-related difficulty in interference resolution among semantically-related stimuli in WM. According to the concentric model of WM (Oberauer, 2002), which distinguishes *the region of direct access* (equivalent to Cowan's focus of attention) and *the focus of attention* in the concentric model, *crosstalk* (i.e., competition among associated items within the region of direct access) will arise when one of them is exclusively brought into *the focus of* *attention* for cognitive operation. Crosstalk is thought to cause difficulty in selectively directing attention toward an item within the region of direct access, similar to refresh-induced inaccessibility. Therefore, observed larger interference effects along a semantic dimension among high-anxiety individuals may represent a difficulty of cognitive control in the process of selectively directing reflective attention from one stimulus or current thought to another semantically similar stimulus or thought. Thus far, it remains unclear exactly how refreshing affects the development of a particular thought, particularly with regards to anxious apprehension or worry. Our component process approach implies that high-anxiety individuals might have difficulty taking alternative ways of viewing a particular event from ongoing thought process, due to the impairment of controlling reflective attention for foregrounding an alternative view (i.e., worriers might have difficulty shifting their focus to less catastrophic ways of viewing a potential future scenario). Further studies are needed to clarify how refresh-induced inaccessibility might be implicated in the development and uncontrollability of unwanted anxiety-provoking thought patterns.

Additionally, Bishop (2009) demonstrated that trait anxiety is associated with decreased recruitment of executive control mechanisms centered at the dorsolateral prefrontal cortex when resolving competition among perceptual stimuli. Investigations of the effect of anxiety on the neural substrates that resolve interference from information held in WM are highly recommended for future studies.

The present results show that for high-anxiety individuals, active distractors held in WM can interfere with perceptual processing under conditions of stronger competition between stimuli (i.e., semantically related lists). Recent studies provide evidence of interference effects from information held in WM on perceptual processing (e.g., Huang & Pashler, 2007). In relation to anxiety, Moriya and Sugiura (2012) demonstrated that the distractors identical to the contents of WM caused greater interference effects upon visual search in individuals with high social anxiety. Contrary to our methodology, the task-irrelevant stimuli in this study (i.e., distractors) were presented visually at the time of responding, such that the content of WM itself was not the distractor used. Nevertheless, high-anxiety individuals can be considered to be more vulnerable to interference from task-irrelevant information actively maintained in WM. Our results suggest that actively maintained information within WM itself could become a distractor that interferes with perceptual processing in conjunction with anxiety

In summary, high-anxiety individuals can have difficulty in controlling both reflective and perceptual attention when a distractor is actively maintained in WM. Further research is needed to clarify the contribution of this difficulty of the development and uncontrollability of unwanted thoughts associated with anxiety.

Chapter 3

Introduction

A wealth of studies demonstrates that anxiety can influence various cognitive processes including higher-order controlled processes as well as early perceptual detection stages. Eysenck and colleagues put forward the attentional control theory of anxiety (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007), which posits that anxiety impairs the functional efficiency of the executive component of working memory (cf. Baddeley, 2007) along with the hypervigilance in sensory-perceptual processing. WM refers to a collection of systems or functions central to active maintenance of information for a brief period of time to organize goal-directed behavior (e.g., Baddeley, 2007). ACT can well accommodate much empirical data from studies investigating the impact of anxiety on cognitive operations using mainly visual-perceptual processing tasks (e.g., Ansari & Derakshan, 2010; Derakshan, Ansari, Shoker, Hansard, & Eysenck, 2009). However, the association between anxiety-related inefficient executive control and performance decrement on higher-order cognitive tasks such as WM task is largely unknown.

Here, I examined one of three sub-processes in inhibitory control over representations in WM; distractor resistance (Freedman & Miyake, 2004; Nee et al., 2012). It is well documented that high levels of anxiety can have close association with distractibility and difficulty concentration (Derryberry & Reed, 2002; Eysenck, 1992; Cisler & Koster, 2010). The mental representations in WM plays a critical role in guiding an adaptive behavior under distracting situations (de Fockert, Rees, Frith & Lavie, 2001; Miller & Cohen, 2001; Postle, 2006; D'Ardenne et al., 2012). Hence, how anxiety affects distractor resistance implicated in WM needs to be investigated in order to clarify the neurocognitive mechanisms of the maladaptive cognition and behavior (e.g., coping) in anxiety.

Previous studies investigating the impact of anxiety on distractor-resistant WM demonstrated that high-anxiety individuals exhibited poorer performance on complex span WM tasks, which are designed to require concurrent processing task while subjects maintain items in WM (e.g., Daneman & Carpenter, 1980; Turner & Engle, 1989). Complex span tasks used in previous studies were traditionally administered at the participant's own pace (Ashcraft & Kirk, 2001; Darke, 1988; Sorg & Whitney, 1992). Consequently, the impact of anxiety-related inefficient control of attention on WM decrement has not been sufficiently examined in relation to time parameters.

The Time-Based Resource-Sharing (TBRS) model of WM, which emphasizes the temporal factor in WM maintenance is one promising model for explaining the association of anxiety and WM decrement (Barrouillet, Bernardin, & Camos, 2004;

Barrouillet, Bernrdin, Portrat, Vergauwe & Comas, 2007). The TBRS model accounts for the determinants of performance on complex span task in the following way: 1) subjects are presented with items they must later recall, 2) while maintaining these items in WM, subjects engage in a processing task which require attentional focus, 3) this diversion of attentional resource from memory item results in a time-based decay of the memory traces for encoding them. As such, performance on complex span task is determined by the temporal constraint on the time spare to direct attention toward the decaying WM items to reactivate them for further retention (refreshing; Cowan, 1999; Raye, Johnson, Mitchell, Greene, & Johnson, 2007). Barrouillet and colleagues have developed a computer-paced complex span task called *continuous processing span task,* which is designed to manipulate the temporal factor for refreshing WM items to limit systematically. Temporal density of processing tasks which compete for attentional resources with WM maintenance is called cognitive load (Barrouillet et al, 2004; 2007). This paradigm has yielded a clear-cut linear association between cognitive load and WM maintenance, demonstrating that greater cognitive load should result in poorer WM maintenance (see Barrouillet & Camos, 2010 for a review).

So far, none of the studies have investigated the impact of anxiety on distractor-resistant WM performance using a complex span task based directly on the TBRS framework for controlling temporal factors concerning the time spare to direct attention toward WM items. Given that high-anxiety individuals would take more time to control attention in the face of attention-demanding intervening task, I predicted that individuals with high levels of trait anxiety would exhibit a difficulty in maintaining WM contents on a continuous processing span task as the temporal restraint on attention control or cognitive load increased.

Method

Participants

Forty-two undergraduate students (age: 18-27 years, mean age = 21.6, 14 females) participated in the experiment in return for compensation. All participants had normal or corrected-to-normal vision. Based on the previous studies such as Ansari et al. (2008) and Derakshan et al. (2009), they were divided into two groups according to whether their trait anxiety scores were above the group median value (high trait-anxiety; HTA; n=23) or below (low trait-anxiety; LTA; n=24), as measured by the trait subscale of the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch & Lushene, 1970). Informed consent was obtained from all patients for being included in the study.

Experimental task

Figure 3.1 shows the diagram of the continuous processing span task. The general feature of the continuous processing span task is that the intervening processing task successively follows each presentation of memory items. In this experiment, alphabetic consonants were presented one by one at a time as memory items and a choice reaction time (CRT) task was employed as processing tasks.

Participants were seated approximately 60 cm. in front of a 17-inch monitor. They were presented with a series of letter-strings in ascending order (from 1 to 7 letters). Each length of letter-string was administered three times. For each trial, each letter was followed by a CRT task. CRT task was employed as a intervening processing task, where a square probe was presented on the upper or lower side of the center fixation cross. A square probe (visual angle, 1.5° on each side) was presented randomly at 9.5° on the upper or lower side of a center fixation cross. Participants were required to respond to a probe presented in the upper side by pressing the “L” key and the lower side by the “A” key. Additionally, three conditions of cognitive load were set up: low, moderate, and high load conditions. Preliminary study revealed that the task required about 398 ms to make a response. Taking this into account, the time interval for the CRT task (i.e., inter-letter interval) was set for 6,500 ms in order to avoid the floor effect in detecting the group differences. Participants were asked to focus on the fixation cross presented on the center of the screen for 1,000 ms at the beginning of each trial, which was followed by a blank screen for 500 ms. Then, the first letter to be remembered was presented for 1,500 ms and replaced by the fixation cross. After a 500 ms delay, a square probe was presented either in the upper or lower side from the cross. The probe was displayed for 2,000 ms (low load), 1,000 ms (moderate load) or 500 ms (high load) and followed by a delay of 1,000 ms, 500 ms or 250 ms (low, moderate or high load) according to the cognitive load condition, which resulted in 2, 4 and 8 response requirements in each processing task sequence. Participants were asked to indicate the position as quickly and accurately as possible by pressing corresponding keys. All participants performed 3 series of 1 to 7 letter-strings each.

[Figure 3.1 on the next page]

Neuropsychological working memory tasks

Reading span task (Daneman & Carpenter, 1980) and the letter-number sequencing task in Wechsler Adult Intelligence Scale third edition (WAIS-III; Wechsler, 1997) were administered for measuring general WM functioning. These tasks were carried out according to a common method except for the stop rules, such that all participants performed the same number of trials.

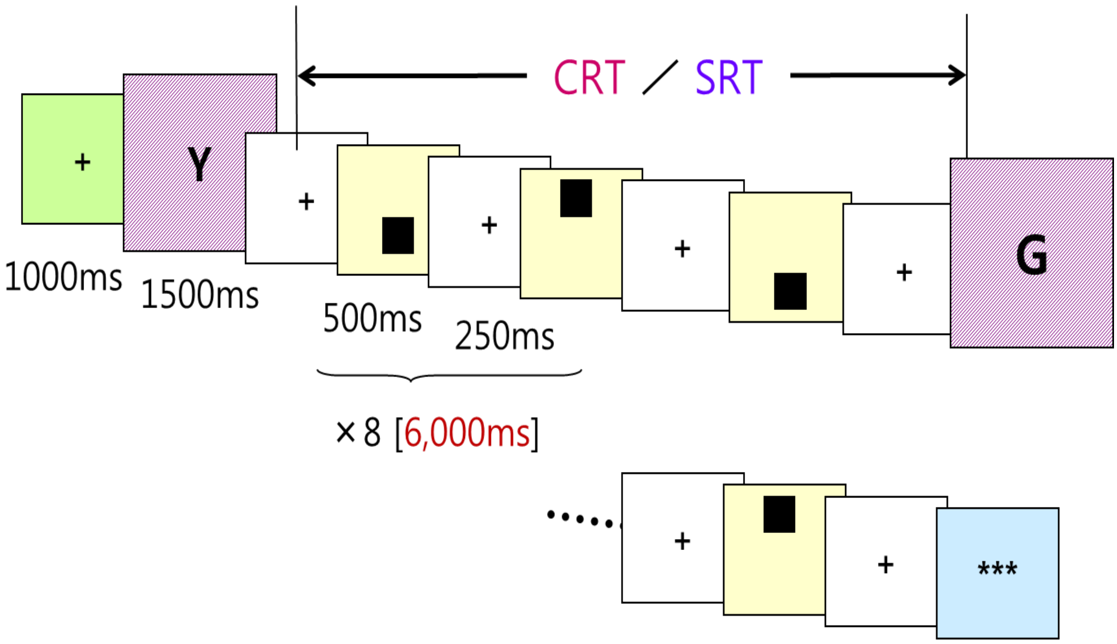

Figure 3.1 Diagram of the continuous processing span task (Barrouillet et al, 2004).
Each Letter for remembering is followed by processing task [Choice Reaction Time (CRT) or Simple Reaction Time (SRT) task]. In CRT task, participants are asked to respond to a probe presented in the upper side by pressing the "L" key and the lower side by the "A" key. In SRT task, simply pressing the space-bar is required irrespective of the probes. Asterisk is presented for the recall cue. Participants are required to recall the letters in the presented order for up to 20 sec. The number of letters is 2 – 7 in ascending order.

Scoring on complex span tasks

I calculated the Partial-Credit Unit (PCU) as an index of WM performance of the continuous processing span task and the reading span task, based on Conway, Kane, Bunting, Hambrick, Wilhelm & Engle (2005). The PCU score denotes the mean proportion of correctly recalled items in a serial order.

Procedure

In the experimental session, participants first completed the trait subscale of the STAI (STAI-T). After a five-minute rest, they filled out the questionnaire battery containing the state subscale of the STAI (STAI-S) and the Tension – Anxiety (TA), Depression – Dejection (D) and Fatigue (F) subscales of the Profile of Mood States (PoMS; McNair, Lorr, & Droppleman, 1971) which assessed temporary mood states.

Then, each participant performed the three conditions of the continuous processing span task (low-, moderate-, and high-load conditions) in random order. Before starting the testing trials, they practiced 3 trials with 2 letters for each condition to ensure that they comprehended the task requirements. Participants were allowed to repeat the practice if they had any doubt about the task (no participants did). All participants performed 21 trials (1 - 7 letters) for each condition. Next, neuropsychological WM tasks (reading span and letter-number sequencing tasks) were administered in random order. Then, they again filled out the same questionnaire battery of mood states.

Results

Questionnaires and general working memory functioning

We first analyzed the data from the questionnaires (see Table 3.1). The HTA group showed significantly higher scores on the STAI-T than the LTA group ($t(40) = 3.02$, p = .0043). Scores of STAI-T were normally distributed in this study (see Appendix). HTA group scored slightly higher (but not statistically significant) and LTA group scored lower than the mean of undergraduates in Japan (reported in Shimizu & Imae, 1981).

No differences were observed in mood measures taken before the experimental task, for the STAI-S (t(40) = 1.37, $p = .178$), and the subscales of the PoMS (Fs < 1.08, ps > .30). The HTA and LTA groups were reliably different from each other for trait anxiety levels but not for mood states taken before and after the experimental task (mood measures after the task; ts < 1.44, ps > .15). Additionally, no differences were observed in the readings span task (HTA; 91.1 v.s. LTA; 92.3: $t(40) = .35$, $p = .73$) and the letter-number sequencing task (HTA; 17.5 v.s. LTA; 17.4: $t(40) = -.11$, $p = .91$).

[Table 3.1 on the next page]

Table 3.1 Mean scores of trait anxiety and negative mood states in High Trait Anxiety group and Low Trait Anxiety group.

	Group			
	High Trait Anxiety (n=23)		Low Trait Anxiety (n=24)	
Measures	Pre-task	Post-task	Pre-task	Post-task
STAI-T	48.1 (6.2)	-	34.8 (7.2)	-
STAI-S	34.3 (6.5)	31.7 (5.9)	26.7 (5.1)	25.7 (5.9)
PoMS-TA	3.8 (1.1)	3.5 (1.0)	3.4 (1.6)	3.7 (2.2)
PoMS-D	4.2 (1.4)	3.9 (1.6)	4.9 (2.6)	4.2 (2.3)
PoMS-F	4.4 (2.3)	4.5 (2.1)	5.1 (3.2)	5.4 (3.4)
Reading span	4.8 (0.6)	-	5.0 (0.7)	-
Letter-number sequencing	18.4 (1.8)	-	18.7 (1.7)	-

note. Standard deviations in parenthesis.

STAI-T = State-Trait Anxiety Inventory - trait form,

STAI-S = State-Trait Anxiety Inventory - state form,

PoMS = Profile of Mood States,

TA = Tension – Anxiety subscale in PoMS,

D = Depression subscale in PoMS,

F = Fatigue subscale in PoMS

Reaction Times on Processing Task

The mean RTs on the CRT tasks were analyzed with a 2 (group) × 3 (cognitive load) mixed design ANOVA. A main effect of cognitive load was significant (F(2,80) = 26.75, p = .002, η^2_p = .43), showing that faster paced presentation resulted in shorter RTs, presumably because the shorter stimulus interval made it easier to sustain attention on the processing task (mean RTs for low, moderate and high load: 401 ms v.s. 387 ms v.s. 369 ms). A main effect of group was not significant (F(1,40) = 0.81, p = .373). An interaction was not observed (F(2,80) = 1.22, p = .300). The results indicate that both groups showed comparable efficiency in the processing task. Accuracy rates were fairly high across all participants (mean accuracy rate: 99.4 %).

Maintenance of Working Memory against Distraction

I calculated the PCU scores for the index of WM maintenance. Figure shows the mean PCU scores and standard errors of the mean for each group and cognitive load condition. A 2 (group) × 3 (cognitive load) mixed design ANOVA was performed with PCU as the dependent variable. A main effect of cognitive load was significant (F(2,80) = 36.74, p < .001, η^2_p = .46). A main effect of group was also significant (F(1,40) = 9.58, p = .003, η^2_p = .21). As expected, an interaction was observed (F(2,80) = 7.39, p = .001, η^2_p = .30), indicating that cognitive load on WM maintenance differentially impacted on the HTA group and LTA group. Bonferroni-corrected pairwise comparisons of group for each cognitive load condition confirmed that the HTA group showed poorer WM performance in the moderate and high load conditions ($t(40) = 2.61$, $p = .038$; $t(40) = 2.94$, $p = .016$, respectively), but not in the low load condition ($t(40) = .32$, *n.s.*), compared with the LTA group .

Finally, correlational analyses were performed to examine the relationship between PCUs and questionnaires (trait anxiety and mood measures). As expected, PCU in high load condition correlated significantly with the score of STAI-T ($r(45) = -.42$, $p < .001$), suggesting that memory recall got worse as the levels of trait anxiety became higher. By contrast, no significant correlations were found on the other experimental conditions with STAI-T (rs $< .14$, $p > .19$).

None of the mood measures taken before and after the experimental task correlated with PCUs (rs $< |.12|$, ps $> .23$).

[Figure 3.2 on the next page]

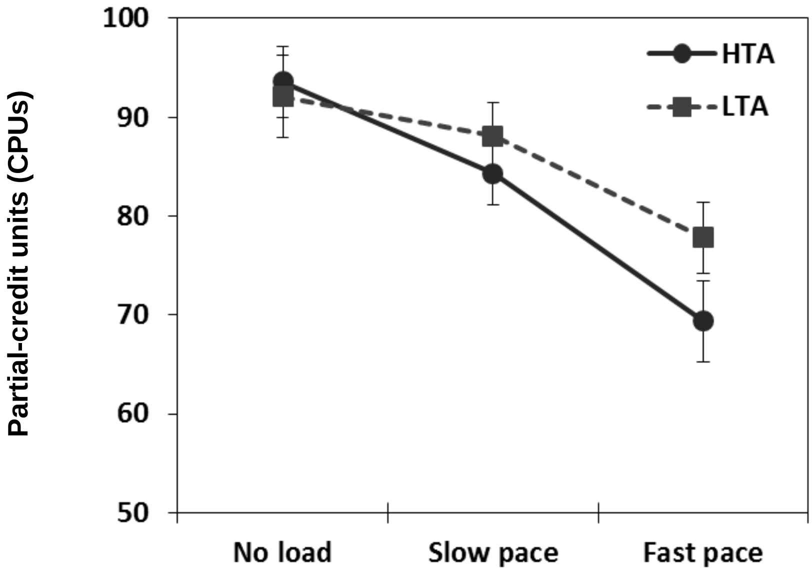

Figure 3.2 Mean Partial-credit unit (PCU) score in High Trait Anxiety (HTA) and Low Trait Anxiety (LTA) groups on each cognitive load condition.
Error bars denotes standard errors of the mean.

Discussion

In the present study, I investigated whether a detrimental effect of trait anxiety on executive control could negatively influence the maintenance of WM contents in a complex span task which controlled time as a limiting factor. I observed that high trait-anxious individuals performed worse, compared to those low in trait anxiety, in the moderate- to high-cognitive-load conditions. There is a clear trend of steeper decline found in the high trait-anxiety group as cognitive load increased.

Our results point to a modulatory effect of cognitive load on the association of anxiety and distractor-resistant WM maintenance. The detrimental effect of anxiety on attentional control has been demonstrated in previous studies, but findings concerning the relation between anxiety and WM maintenance, especially verbal domain, are mixed (e.g., Eysenck, Payne & Derakshan, 2005; Walkenhorst & Crowe, 2009).

The current study demonstrates that the time-constraint nature of cognitive load was crucial for modulating the association of anxiety and WM maintenance. Eysenk and Calvo (1992) suggest that task difficulty is one crucial factor for detecting the detrimental effect of anxiety on cognitive task performance. Our findings point out that one element of task difficulty is the severity of temporal constraints limiting the available time to refresh WM items as TBRS theory postulates.

Impaired distractor-resistant WM maintenance in the HTA group was selectively related to trait anxiety but not to state anxiety or other negative mood states. Previous studies demonstrated that state anxiety could strengthen stimulus-driven attention, and would not affect executive control (e.g., Pacheco-Unguetti, Acosta, Callejas & Lupiáñez, 2010). In line with this finding, in the current study the levels of state anxiety were not predictive of performance on the continuous processing span task which depends heavily on executive control. Other negative mood states such as depression and fatigue also showed no relation to WM performance. Given that the scores on these mood measures were fairly low irrespective of the level of trait anxiety, it is possible that intense negative mood might affect executive processes under stressful and/or emotion-eliciting situations. This possibility is becoming further elucidated in recent studies (e.g., Vytal, Cornwell, Letkiewicz, Letkiewicz & Grillon, 2013).

To the best of our knowledge, this is the first investigation based on the TBRS theory of the detrimental effect of anxiety on WM tasks. However, our findings have some limitations. First, even though TBRS theory assumes that the between-task shifting is crucial, focus shifting within WM items is also time-consuming (Garavan, 1998; Oberauer, 2002; Raye et al., 2007). Actually, Camos et al. (2009) demonstrated that refreshing WM items contributed to maintenance of verbal memory materials independently of phonological rehearsal. Therefore, further studies are needed to elucidate the role of focus shifting in performing the WM tasks, and especially the effect of anxiety on this reflective process. Secondly, although the HTA and LTA groups were equivalent in neuropsychological WM tasks, measures of general intelligence or other personality traits were not included in our study. As a consequence, baseline general cognitive ability and personality traits relating to anxiety were not controlled. Future studies investigating the association of anxiety and cognition should include these variables for controlling extraneous variables.

It is worth noting that the decrement of distractor-resistant WM maintenance in high-anxiety individuals would be related to their performance involving higher-order cognition, such as reading (Calvo & Eysenck., 1996), reasoning (MacLeod & Donnellan, 1992; Markham & Darke, 1991) or math exam (Ashcraft & Kirk, 2001). High-anxious individuals can be suffered from distractibility and difficulty concentrating on task at hand. Therefore, executive function trainings including attention and WM are now emerging treatment for the cognitive dysfunction(s) in anxiety (e.g., Bomyea & Amir, 2011). Predicting the negative impact of anxiety on higher-order cognition from lower level executive processes (i.e., attention, working memory) might be one promising direction for further establishing the clinical methodology of cognitive trainings for high-anxiety individuals.

Chapter 4

Introduction

A large body of study has demonstrated that anxiety (mainly trait anxiety) is tightly linked to distractibility (Derryberry & Reed, 2002; Eysenck, 1992) and decreased executive control for interference resolution in visual/ perceptual processing (Ansari & Derakshan, 2010; Bishop, 2009). In addition, as demonstrated in previous chapters, anxiety can impair resolution of interference acting on the representation(s) in WM (also see Stout et al., 2012; Qi et al., 2014 for decreased filtering function of WM in anxiety). In this chapter, another type of important interference within WM would be investigated in relation to trait anxiety, namely, proactive interference (Jonides & Nee., 2006). Proactive interference refers to the intrusion of task-irrelevant memory content, which is previously relevant but now no longer relevant to the goal, into the current memory set (Hasher & Zacks, 1988). The importance of proactive interference as a fundamental constraint in memory and cognition is highlighted in previous studies implicating that it can act as a cause of forgetting from WM (Keppel & Underwood, 1962). Moreover, cognitive control for resisting or overcoming the influences of distracting memory contents is considered as one of the subcomponents in inhibition process subserved by the central executive of WM (intrusion resistance; Freedman & Miyake., 2004; Nee et al., 2012). Thus, if anxiety disrupts the executive control for intrusion resistance, high-anxiety individuals would be more susceptible to interference from no longer relevant memory representations, which could result in development of unwanted thought (Qui et al., 2014).

As for the association of anxiety with intrusive thought, Clark (2000) specify three major types of content: Worry intrusion refers to anxious apprehensions for current concerns anticipating negative results in near future. It arises without intention and can be triggered by internal/mental representations. Obsessional intrusion refers to mental contamination occupied with repugnant, aggressive, sexual, or religious content of thought. Trauma-related intrusion is the ‘flash-back’ of past traumatic experience. These are highly relevant across wide range of anxiety disorders, evoking emotional distress, difficulty of concentration, and sleep disturbance (Kertz, Bigda-Peyton, Rosmarin, & Björgvinsson, 2012). From a neurocognitive perspective, these features suggest that intrusion reflects anxiety-related difficulties in preventing unwanted information (usually threatening ones) from being active within WM (Stout et al., 2012; Qi et al., 2014). Hence, high-anxiety individuals could be associated with decreased recruitment of neural mechanism(s) for interference resolution when currently irrelevant information intrudes into the memory set within WM.

A meta-analysis of neural substrates for intrusion resistance, specifically controlling over the proactive interference indicates that left ventrolateral prefrontal cortex (VLPFC) plays a critical role in the resolution of proactive interference (Nee et al., 2012; also see Jonides & Nee., 2006 for a review).

Recent neuroimaging studies examining the neurocognitive underpinnings of intrusion resistance often use the recent-probes task, which is the modification version of the Sternberg item recognition task (Sternberg, 1966) for building up proactive interference within WM (e.g., D'Esposito et al., 1999; Jonides et al., 2000). In a recent-probes task, small set of stimuli (letters or words) is presented to remember for a short period of time, then followed by a recognition probe for which participants are required to judge whether it is a member of the memory set. Recognition probes can be classified into four types; it is either a member of the memory set (positive) or not (negative). Also, a probe can be a member of the memory set in the previous trial (recent probe) or not (non-recent probe). Hence, a recent-probes task consists of four types of probes; *recent positive, recent negative, non-recent positive,* and *non-recent negative* ones. The typical finding of this task is that longer latencies and increased error rates are observed when rejecting recent negative probes compared to non-recent negative probes (Monsell, 1978; McElree & Dosher, 1989). This performance decrement is thought to be an indicator of memory confusion caused by intrusion of information presented in previous trial into the current memory set.

Given that anxiety disrupts top-down/executive control for interference resolution (Eysenck et al., 2007), and anxiety is tightly associated with unwanted intrusive thought irrespective of current external context (Clark, 2000), it was predicted that, compared to low-anxiety individuals, high-anxiety individuals would have more difficulty overcoming interference from the information

Method

Participants

Forty undergraduate students (age: 18-24 years, mean age = 19.3, 22 females and 18 males) participated in the experiment in return for compensation (about $10 US). All participants had normal or corrected-to-normal vision. On the basis of trait anxiety as measured by trait subscale scores on the State-Trait Anxiety Inventory (STAI; Shimizu & Imae, 1981; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), they were divided into two groups according to whether scores were above or below the median value (HTA and LTA groups).

Experimental task

Figure 4.1 presents the diagram of the task. Participants performed an item-recognition task in which they were instructed to judge whether the probe matched the target memory set of four consonants. Four types of trial were created according to the nature of probes; *recent positive, recent negative, non-recent positive,* and *non-recent negative* ones. Each participant performed a total of 128 trials in the proportion of 5 recent negative: 4 non-recent negative: 3 recent positive: 4 non-recent positive (D'Esposito, Postle, Jonides, & Smith, 1999). The number of positive and negative probes was roughly matched in order to suppress anticipatory responses.

Each trial began with a fixation cross presented for 1,000 ms, followed by four Alphabets for remembering for 950 ms. Then the letters disappeared and a fixation remained on screen for 7,050 ms, followed by a recognition probe letter for 1,500 ms. Participants were asked to judge as quickly and accurately as possible whether the recognition probe was a member of memory set by pressing either 'L' key (indicating Yes) or 'A' key (indicating no). A 3,000, 5,000, or 7,000 ms interval separated each trial from the next. There were a total of 128 trials.

[Figure 4.1 on the next page]

Neuropsychological working memory tasks

Reading span task (Daneman & Carpenter, 1980) and the letter-number sequencing task

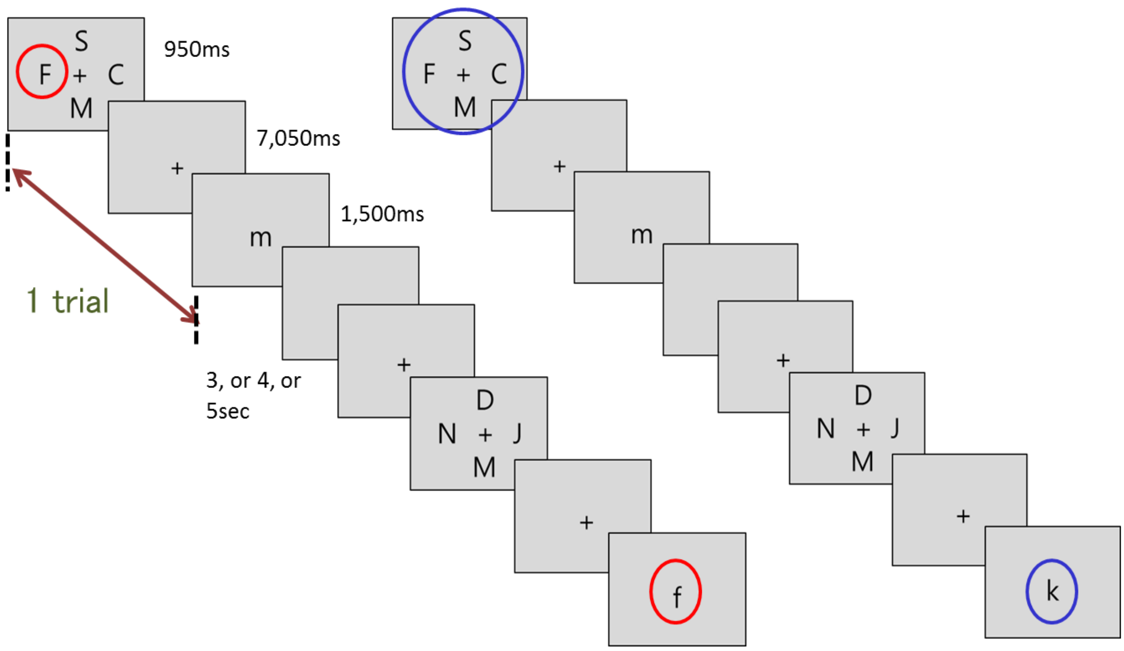

Figure 4.1 Task diagram of the recent-probes task.
Target items were presented for 950 ms followed by a 7,050 ms delay period. This interval was followed by a probe letter for 1,500 ms that either was recently presented (recent trial) or was not recently presented (non-recent trial). Note that, in the recent negative trial, the probe letter ‘‘F’’ is not in the target set of that trial but that it is in the target set of the previous trial.

in Wechsler Adult Intelligence Scale third edition (WAIS-III; Wechsler, 1997) were administered for measuring general WM functioning. These tasks were carried out according to a common method except for the stop rules, such that all participants performed the same number of trials.

Apparatus

The experiment was conducted on a Dell Dimension 3100 computer with an Intel Pentium 4 central processor. The stimuli were presented on a 17-inch Sony CPD-E230 monitor, using E-prime software.

Procedure

Upon arrival at the laboratory, participants first completed the trait subscale of the STAI (STAI-T). After a five-minute rest, they filled out a questionnaire battery that included the state subscale of the STAI (STAI-S) and the Tension – Anxiety (TA), Depression – dejection (D) and Fatigue (F) subscales of the Profile of Mood States (PoMS; McNair, Lorr, & Droppleman, 1971; Yokoyama, 2005), which was used to assess temporary mood states.

Each participant performed the recent-probes task after questionnaire completion. Before the test trials began, each participant performed three practice trials for each condition to ensure comprehension of the task requirements. Participants were allowed to repeat the practice if they had any doubts about how to perform the task (although no participant did so). Participants filled out the same questionnaire battery (excluding the STAI-T) again upon completion of the 120 test trials. Participants were fully debriefed at the end of the session. Informed consent was obtained from each participant.

Results

On the basis of STAI-T scores, participants were divided into two groups via a median split: HTA and LTA groups. To validate this grouping procedure, an independent *t*-test of group was conducted with STAI-T scores as the dependent variable. As shown in Table 4.1, the HTA group had significantly higher STAI-T scores than the LTA group, $t(38) = 2.96$, $p = .010$, showing that these groups were reliably different from each other regarding trait anxiety. Scores of STAI-T were normally distributed in this study (see Appendix). HTA group scored slightly higher (but not statistically significant) and LTA group scored lower than the mean of undergraduates in Japan (reported in Shimizu & Imae, 1981).

Next, scores on mood measures taken before and after the experimental task were compared between groups. No differences were found for mood measures including state anxiety, *t*s < 1.71, *p*s > .190.

[Table 4.1 on the next page]

RTs on each task condition were analyzed (see Figure 4.2). Each participant's representative values were the means of RTs within the experimental conditions. Because positive probe conditions are not germane to our prediction, RTs in these trails were collapsed across recent and non-recent conditions, resulting in three trial types; recent negative, non-recent negative, and positive. A 2 (group) × 3 (probe type) mixed design ANOVA was administered with RTs as dependent variable. Significant main effect of probe type was observed on RTs, $F(2, 78) = 10.36$, $p = .0001$, $\eta^2_p = .21$. Follow-up *t*-tests with Bonfferoni correction indicate that longer latencies were observed when rejecting recent negative probes compared to non-recent negative probes, $t(38) = 3.38$, $p = .0017$, suggesting the successful introduction of proactive interference (D'Esposito et al., 1999; Monsell, 1978; McElree & Dosher, 1989).

[Figure 4.2 on the next page]

Table 4.1 Mean scores of trait anxiety and negative mood states in High Trait Anxiety group and Low Trait Anxiety group.

	Group			
	High Trait Anxiety (n=20)		Low Trait Anxiety (n=20)	
Measures	Pre-task	Post-task	Pre-task	Post-task
STAI-T	46.7 (6.5)	-	33.6 (5.7)	-
STAI-S	31.2 (7.7)	30.6 (5.7)	29.3 (7.3)	28.7 (5.8)
PoMS-TA	4.3 (1.8)	4.2 (1.4)	4.7 (2.1)	4.3 (2.2)
PoMS-D	3.7 (2.0)	4.2 (2.3)	4.6 (2.6)	3.9 (2.8)
PoMS-F	4.8 (2.9)	4.6 (2.5)	3.4 (1.9)	4.6 (2.4)
Rading span	5.1 (0.8)		4.9 (0.5)	
Letter-number sequencing	19.1 (1.3)		19.2 (1.4)	

note. Standard deviations in parenthesis.

STAI-T = State-Trait Anxiety Inventory - trait form,

STAI-S = State-Trait Anxiety Inventory - state form,

PoMS = Profile of Mood States,

TA = Tension – Anxiety subscale in PoMS,

D = Depression subscale in PoMS,

F = Fatigue subscale in PoMS

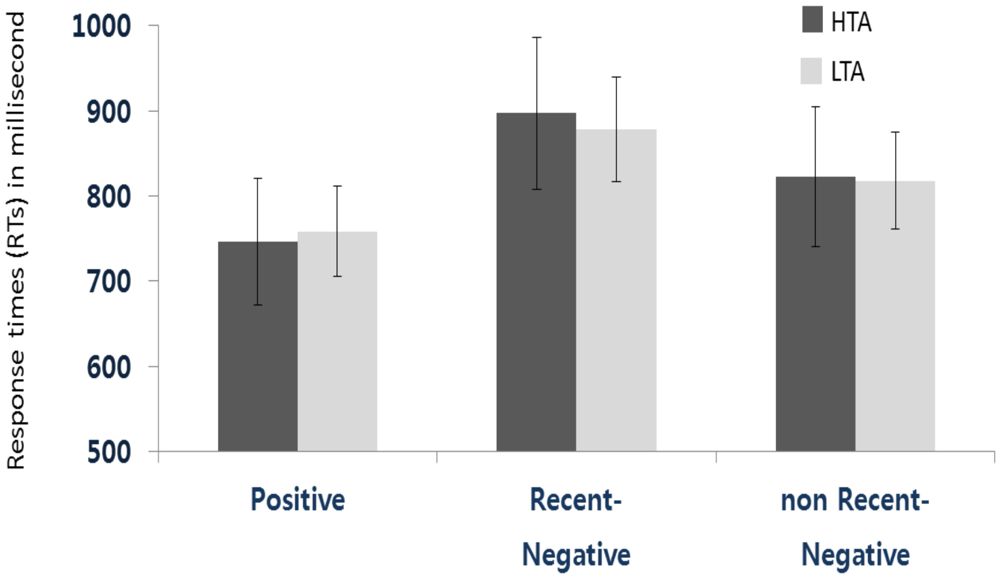

Figure 4.2 Mean response times (RTs in msec) for High Trait-Anxiety (HTA) and
Low Trait-Anxiety (LTA) groups on the recent-probes task.
Error bars denote standard errors of the mean.
Horizontal axis represents task conditions: positive, recent-negative, and non-recent negative.

Regarding the impact of anxiety on intrusion resistance, there were no main effect or interaction relating to anxiety, Fs < 1.43, ps > .23. These results indicate the comparable efficiency of task performance in HTA and LTA groups across conditions. None of scores on the questionnaires (trait anxiety and mood measures) correlated with RTs (*r*s < |.26|, *p*s > .12). Accuracy rate on the task were fairly high across all participants (mean accuracy rate; 98.1 %).

Discussion

The present study examined whether the elevated levels of trait anxiety negatively affect resolution of proactive interference in WM, or intrusion resistance. I was motivated to examine this question in terms of the fact that high-anxiety individuals often experience difficulty suppressing the unwanted intrusive thought or anxious apprehension (i.e., worry), which would arise irrespective of the current context (e.g., Borkovec, Robinson, Pruzinsky, & DePree, 1983; Hirsch & Mathews, 2012). In the recent-probes task, high-anxiety individuals showed comparable performance irrespective of task conditions. Additionally, contrary to our prediction, high-anxiety individuals did not show difficulty, relative to those low in anxiety, in responding *recent-negative* probes (i.e., intrusion resistance). These results imply that trait anxiety does not necessarily have adverse impact on the process of resolving proactive interference, as far as alphabet or emotionally neutral verbal material is used for memory set.

According to Bishop (2007), elevated levels of anxiety can be associated with decreased recruitment of lateral prefrontal regions, such as the dorsolateral prefrontal cortex (DLPFC) and the ventrolateral prefrontal cortex (VLPFC), which are implicated in top-down control for interference/competition resolution. In addition, VLPFC is known to play a central role in resolving proactive interference or intrusion resistance (Nee et al., 2012). Given these facts, it might follow that high-anxiety individuals could be more vulnerable to memory intrusion from no longer relevant representations in WM, due to their decreased recruitment of the neural mechanism(s) for suppressing intrusion.

Although our results did not support for the predicted difficulty of intrusion resistance in high-anxiety group, there are a small number of evidence for the association of anxiety with impaired intrusion resistance. In this regard, for example, Borkowski and Mann (1968) demonstrated that anxiety disrupts short-term memory maintenance in the face of (but not in the absence of) proactive interference, suggesting that high-anxiety individuals could be more vulnerable to unwanted intrusion from prior information. Regarding the memory decrement associated with anxiety, however, they proposed that anxiety depleted the opportunity for phonological rehearsal to retain short-term memory because of their frequent task-irrelevant worrisome thought. Consistent with this proposal, recent studies reported that worry and task-irrelevant negative thought, especially in verbal form rather than imagery, interfere with cognitive resources which are vital for top-down/executive control for interference resolution (Beckwe, Deroost, Koster, Lissnyder, & Raedt, 2014; Derakshan & Eysenck, 1998; Hayes, Hirsch, & Mathews, 2008; Rapee, 1993; Richards, French, Keogh, & Carter, 2000; Stefanopoulou, Hirsch, Hayes, Adlan, & Coker, 2014). In neuroimaging study, Kühn, Schmiedek, Brose, Schott, Lindenberger, and Lövden (2013) demonstrated that individual differences in experiencing intrusive thought are correlated with activity in the left inferior frontal gyrus (IFG) including the Broca's language-production area. IFG is also implicated in the resolution of proactive interference (Nee et al., 2012). Additionally, these findings also imply that intrusive thought is represented mainly in verbal form rather than imagery in the brain. These findings seem to indirectly support for the argument of cognitive interference of worry discussed in Borkowski and Mann (1968).

Herein, it is reasonable to assume that anxiety itself is not the direct cause of (predicted) poor top-down control for intrusion resistance, but rather is directly associated with poor emotion regulation reflected in decreased VLPFC activation in the face of interference (Bar-Heim et al., 2012). From this view, high-anxiety individuals can generally (or habitually) interpret task-irrelevant thought as more distressing fashion due to their inability to exert efficient emotion regulation (Hirsch & Mathews, 1997; 2000), resulting in the development of negative or threatening representation in mind. In fact, a large body of literature arguably indicates that high-anxiety individuals are more likely to experience intrusive "negative" thought, compared to those low in anxiety (e.g., Clark & Hemsley, 1985; Munoz, Sliwinski, Smyth, Almeida, & King, 2013; Purdon & Clark, 1994). As a result, preoccupation with intrusive negative thought would interfere with cognitive resources for top-down/executive control (cognitive interference of worry: also see Eysenck & Calvo, 1992; Sarason. 1984; 1988). Hence, (predicted) poor intrusion resistance would not be the 'cause' of intrusive thought, but rather the 'result' of it.

In summary, unlike the association of anxiety with decreased interference resolution in WM (Chapter 2) and poor distractor resistance for maintaining WM contents (Chapter 3), anxiety is not necessarily the cause of poor intrusion resistance. Thus far, the mechanism and process of the development of intrusive thought relating to anxiety are poorly understood. Further studies are needed to identify the mechanism through which maladaptive intrusive thought is developed for treating this ubiquitous feature in various types of anxiety.

Chapter 5

Introduction

A wealth of evidence indicates that individual differences in trait anxiety can be associated with alterations in cognitive functioning including distractibility and interference/competition resolution (Bar-Heim et al., 2007; Cisler & Koster, 2010 for reviews). It has been postulated that anxiety impairs cognitive functioning through tis disruptive effect on the top-down/executive control of attention (Bishop, 2009; Eysenck et al., 2007). ACT identifies a type of executive function on which anxiety negatively affects as inhibition and attentional set shifting (Eysenck et al., 2007). As focusing on interference resolution, inhibition is an important regulatory function that uses attentional control to prevent processing resources from allocation to internal or external task-irrelevant information in order to exert efficient goal-directed behavior. It is assumed to play a central role in a wide range of cognitive domains including selective attention, memory, and higher-order cognition (e.g., problem solving) in the face of interference/competition (MacLeod et al., 2003 for a review). Therefore, it is of great importance to understand the neurocognitive mechanisms underlying the maladaptive cognition and behavior in anxiety.

As I have described in previous chapters, I exclusively focused on the associations of trait anxiety with three types of executive control: Refreshing (chapter 2), distractor resistance (chapter 3), and intrusion resistance (chapter 4), which are the cognitive operations responsible for selectively accessing or maintaining task-relevant mental representation(s) within WM in the face of interference/competition from various sources of distractors. Assuming that trait anxiety can negatively affect the executive control mechanism(s) located in the lateral PFC necessary for interference/competition resolution (Bishop, 2009; Eysenck el al., 2007), there could be anxiety-related regulatory alterations in the brain activity when the cognitive control for interference/competition resolution is required.

Although there is a common theoretical assumption that the top-down/executive control of attention is impaired in high-anxiety individuals, opposite predictions about the association of anxiety and neural activity can be made. While the neurocognitive theory of Bishop (2007, 2009) postulates that high levels of anxiety can be associated with reduced activation in brain regions relating to top-down/executive control (i.e., lateral PFC), Eysenck and colleagues (Eysenck et al., 2007; Eysenck & Derakshan, 2010) suggest that high-anxious individuals would show increased activation in the same brain regions, due to a compensatory strategy or additional ‘effort’ to attain a given level of performance. In fact, empirical data are rather inconsistent. There are several studies observing an increased neural activation in executive control regions in highly-anxiety individuals (e.g., Ansari & Derakshan, 2011; Basten et al., 2011; Gray & Braver, 2002; Telzer et al., 2008), others reported the opposite pattern of results in the same brain regions (e.g., Bishop, 2007; 2009; Bishop et al., 2004; Klumpp et al., 2011).

Recently, a pivotal study on the impact of anxiety on verbal WM processes has provided findings that implicate a vital role for memory load in the association between anxiety and cognitive control (Vytal, Cornwell, Arkin, & Grillon., 2012). They reported that anxiety-related performance decrement was observed only when the memory load was relatively low. By contrast, when the cognitive load was high enough, performance did not differ in relation to anxiety. These findings highlight the importance of memory load in the study of emotion–cognition interactions (In that point, our study in chapter 3 manipulated “cognitive/processing” load, not the memory load). In response to their study, I examined whether the activities in prefrontal regions would alter in relation to trait anxiety under interfering situations with high and low memory load.

For measuring the prefrontal activities of interest, I employed the Near-Infrared Spectroscopy (NIRS), which can detect the concentration changes of hemoglobin by non-invasive manner. Although NIRS is only able to measure activities in the surface cortical areas, several studies have recently attempted to capture the prefrontal cortical activity when engaged in top-down/executive control for interference resolution (Ozawa et al., 2014; Takizawa, Nishimura, Yamasue, & Kasai, 2013).

In the current study, selective refreshing task (chapter 2) was adopted for interference/competition resolution in order to evaluate the anxiety-related alterations in brain regions for top-down/executive control, because refreshing is a highly simple cognitive operation and intensively examined its neurocognitive underpinnings (Ray et al., 2007; 2008). Moreover, two memory-load conditions were set in these tasks (details in the Method section). Given the findings of Vytal et al (2012), I expected to detect the anxiety-related regulatory alterations in prefrontal activity along with performance decrement under relatively low memory-load condition. By contrast, anxiety would have no impact on the regulation of prefrontal activity as well as task performance when the load is high.

Method

Participants

Twelve undergraduate students (age: 19-32 years, mean age = 22.2, 6 females and 6 males) participated in the experiment. All participants were right-handed and had normal or corrected-to-normal vision. On the basis of trait anxiety as measured by trait subscale scores on the State-Trait Anxiety Inventory (STAI; Shimizu & Imae, 1981; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), they were divided into two groups according to whether scores were above or below the median value in this sample (HTA and LTA groups).

NIRS sensor and data acquisition

The OEG-16 (Spectratech Inc., Tokyo) was employed in the present study. This NIRS sensor can easily attached on the forehead, and record the concentration changes of hemoglobin from 16 channels (Figure 5.1). The emission and detection probes were 3cm apart from each other, and all of the probes were set in a 15 × 3cm matrix area. The OEG-16 utilizes two types of wavelengths (approximately 770 nm and 880 nm), to estimate the changes in absorption rate of hemoglobin at a depth approximately 3cm below the scalp (Watanabe, Maki, Kawaguchi, Yamashita, Koizumi, & Mayanagi ., 2000). The OEG-16 can record the concentration changes of oxygenated hemoglobin (oxy-Hb), and deoxygenated hemoglobin (deoxy-Hb). In this study, I analyzed only the data of oxy-Hb, because it is known to be sensitive to changes in cerebral blood flow (Hoshi et al., 2001), and is also known to have ample correlation with blood-oxygen-level-dependent (BOLD) signals (Sato, Yahata, Funane, Takizawa, Katura et al., 2013; Strangman, Culver, Thompson, & Boas., 2002). The sampling rate was 655ms. The center of the probe holder was placed on Fpz (the midpoint between Fp1 and Fp2) in accordance with the International 10/20 System. The channels covered inferior frontal gyrus (IFG), middle fontal gyrus (MFG), superior frontal gyrus (SFG), and the lateral orbitofrontal area.

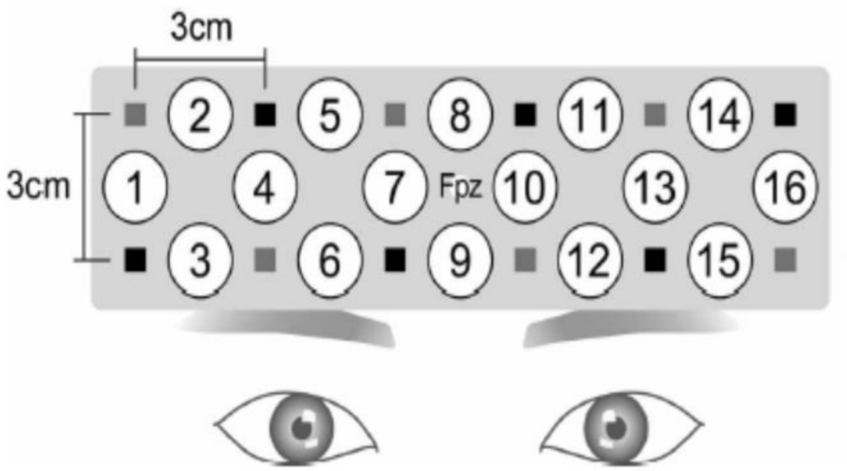

Figure 5.1 The Near-infrared spectroscopy (NIRS)
The Spectratech OEG-16 NIRS system consisted of six emission probes (gray squares) and six detection probes (black squares) which form sixteen channels. The center of the probe holder was placed on Fpz in the International 10/20 system.

Experimental task

The selective refreshing task was employed in this study (Higgins & Johnson, 2009; Ray et al., 2007). The task and verbal materials were basically the same as in chapter 2, but some arrangements were added: First, in order to evaluate the modulatory role of memory load in the association of anxiety with prefrontal activity in executive control, three (low load) and five (high load) word lists were made. Secondly, interference and no-interference blocks were set for the NIRS study. In the interference block, twelve trials composed of 10 interference trails (e.g., *refresh-refresh*) and 2 no-interference trails (e.g., *repeat-refresh* and *repeat-read*) were performed along with each word-list length. In contrast, in the no-interference block, 10 no-interference trails and 2 interference trails were performed along with each word-list length.

Neuropsychological working memory tests

Reading span task (Daneman & Carpenter, 1980) and the letter-number sequencing task in Wechsler Adult Intelligence Scale third edition (WAIS-III; Wechsler, 1997) were administered for measuring general WM functioning. These tasks were carried out according to a common method except for the stop rules, such that all participants performed the same number of trials.

Procedure

Upon arrival at the laboratory, participants first completed the trait subscale of the STAI (STAI-T). After a five-minute rest, they filled out a questionnaire battery that included the state subscale of the STAI (STAI-S) and the Tension – Anxiety (TA), Depression – dejection (D) and Fatigue (F) subscales of the Profile of Mood States (PoMS; McNair, Lorr, & Droppleman, 1971; Yokoyama, 2005), which was used to assess temporary mood states.

Each participant performed the selective refreshing task on varied memory load and interference conditions after questionnaire completion. Before the test trials began, each participant performed three practice trials for each condition to ensure comprehension of the task requirements. Participants were allowed to repeat the practice if they had any doubts about how to perform the task (although no participant did so). Then the rest period of 30sec was inserted prior to the testing blocks. The implementation order of each testing blocks was as follows; the selective refreshing task with low memory load, that with high memory load. Then the 60 sec rest-intervals were inserted between the each memory load conditions. In all the memory load conditions, non-interference blocks preceded the interference blocks. In sum, each participant would perform 4 blocks for testing (2 memory load conditions × 2 interference conditions).

Participants filled out the same questionnaire battery (excluding the STAI-T) again upon completion of the experimental tasks. Participants were fully debriefed at the end of the session. Informed consent was obtained from each participant.

Results

On the basis of STAI-T scores, participants were divided into two groups via a median split: High trait-anxiety (HTA; n=6) and low trait-anxiety (LTA; n=6) groups. To validate this grouping procedure, an independent *t*-test of group was conducted with STAI-T scores as the dependent variable. As shown in Table 5.1, the HTA group had significantly higher STAI-T scores than the LTA group, $t(10) = 2.48$, $p = .032$, showing that these groups were reliably different from each other regarding trait anxiety. Next, scores on mood measures taken before and after the experimental task were compared between groups. No differences were found for mood measures taken before and after the experimental tasks, *t*s < 0.44, *p*s > .670.

Behavioral data analyses

Table 5.2 shows the response times (RTs on Task 2) in each experimental condition. I performed a 2 (group: HTA vs. LTA) × 2 (memory load: high vs. low) × 2 (interference: interference vs. non-interference) mixed deign ANOVA with group as between subject factor and RTs in the selective refreshing task (Task 2) as dependent variable. There were main effects of memory load and interference condition (F(1, 10) = 12.27, p = .011, η^2_p = .36; F(1, 10) = 9.62, p = .022, η^2_p = .54, respectively), suggesting that participants generally took more time to respond in high memory load condition than in low memory load condition, and in the interference block than in the non-interference block. These results indicate that effects of memory load and interference (i.e., refresh-induced inaccessibility) in WM were successfully introduced. Contrary to the results of Vytal et al (2012), the interaction of group × memory load was not significant on these behavioral data (F(1, 10) = 1.98, p = .38) , but instead a main effect of group was significant, indicating a general slowing of HTA group (F(1, 10) = 7.33, p = .044, η^2_p = .12). Other interactions were not significant (Fs < 2.41, ps > .30).

[Table 5.1 & 5.2 on the following pages]

Near-Infrared Spectroscopy data analyses

To increase the signal-to-noise ratio, data from each channel were converted into a z-score because raw data represent relative values of changes in oxy-Hb concentration, and thus cannot be compared directly across participants (Matsuda & Hiraki, 2006). The z-scores were calculated using the mean and standard deviation of changes in the oxy-Hb concentrations during the last 10sec of the rest period (i.e., baseline value was

Table 5.1 Mean scores of trait anxiety and negative mood states

in High Trait Anxiety group and Low Trait Anxiety group.

	Group			
	High Trait Anxiety (n=6)		Low Trait Anxiety (n=6)	
Measures	Pre-task	Post-task	Pre-task	Post-task
STAI-T	44.3 (9.2)	-	31.5 (10.2)	-
STAI-S	28.6 (14.3)	26.7 (11.1)	26.0 (7.9)	28.3 (10.3)
PoMS-TA	3.4 (1.5)	3.3 (1.4)	3.6 (1.6)	3.4 (2.0)
PoMS-D	3.9 (1.8)	3.9 (1.4)	3.2 (1.6)	3.6 (1.3)
PoMS-F	4.0 (1.3)	4.2 (2.1)	4.5 (2.4)	4.4 (3.7)
Reading span	5.1 (0.4)	-	5.0 (0.7)	-
Letter-number sequencing	17.4 (1.8)	-	18.0 (1.9)	-

note. Standard deviations in parenthesis.

STAI-T = State-Trait Anxiety Inventory - trait form,

STAI-S = State-Trait Anxiety Inventory - state form,

PoMS = Profile of Mood States,

TA = Tension – Anxiety subscale in PoMS,

D = Depression subscale in PoMS,

F = Fatigue subscale in PoMS

Table 5.2 Mean response times (msec) and standard deviations for the High and Low Trait-Anxiety groups in each experimental conditions.

	Interference		Non-interference	
WM load	High	Low	High	Low
HTA	1,156 (108)	769 (76)	899 (116)	597 (87)
LTA	1,028 (119)	713 (89)	884 (95)	612 (72)

Note. Standard deviations in parenthesis.

set 0 and standard deviation was 1). Additionally, changes in oxy-Hb concentrations in each channel were averaged into a single value in order to employ the significance test of activation level compared to the baseline (i.e., rest period), and examine the group differences (HTA vs. LTA) in brain activity under interfering situations.

Regional cerebral blood flow in each experimental task

To test in which channels significant brain activations were observed depending on the task conditions, one-sample *t*-tests with the significance level of 0.0015 [0.05 / 32 (i.e., 16 channel * 2 memory load)] were performed, irrespective of trait anxiety. In the interference block, a series of analyses indicated that significant brain activations were observed on the channel 3, 4, 11, 13, 14, 15, and 16 in high WM-load condition (ts > 4.36, ps < .0015), and channel 2, 6, 14, 15, and 16 in that of low WM load (ts = 4.41, ps < .0013). While on the other hand, in the non-interference block, significant activations were detected only on channel 13 and 14 both in high and low WM-load conditions (ts > 4.42, ps < .0013), suggesting that cortical regions for short-term maintenance were only implicated in the non-interference conditions.

Selection of channels of interest (COI)

Based on the results obtained above as well as Nee et al (2012), I determined the COI as channel 14, 15, and 16 for further analyses.

Figure 5.2 shows the waveforms of each COI on the interference with high WM condition. A 2 (group; HTA vs. LTA) × 2 (WM load: high vs. low) × 2 (interference: interference vs. non-interference) mixed deign ANOVA was performed with block means of the z-score as dependent variable for each COI. The significance level set 0.017 [0.05/3(COIs)] for each COI. I focused fundamentally on the interaction in which the group factor (i.e., anxiety level) was involved.

Channel 14:

There was a significant two-way interaction of WM load × interference ($F(1, 11) = 12.36$, $p = .0096$, $\eta^2_p = .23$), which was qualified by three-way interaction of group × WM load × interference ($F(1, 11) = 11.12$, $p = .013$, $\eta^2_p = .20$). Follows-up *t*- tests revealed that HTA group showed greater activation in the interference condition with high WM load ($t(10) = 3.62$, $p = .022$, Bonfferoni-corrected), but the group differences on the other conditions were not observed (*t*s < 1.65, *p*s > .58, Bonfferoni-corrected). A main effect of group was not significant ($F(1, 11) = 3.91$, $p = .14$).

Channel 15:

On this channel, the significant interaction of memory load × interference (*F*(1, 11) =

13.66, $p = .007$, $\eta^2_p = .32$) was qualified by group ($F(1, 11) = 20.51$, $p = .0016$, $\eta^2_p = .33$). Follow-up *t*-tests with Bonferroni correction revealed that HTA group showed greater activation under interference when the WM load was high ($t(10) = 3.82$, $p = .029$), and weaker activation under interference when the WM load was low ($t(10) = 3.43$, $p = .050$), compared to LTA group. By contrast, no group differences were found under non-interference conditions, irrespective of WM load (*t*s < 1.71, *p*s > .44). Next, I observed the significant main effects of memory load and interference ($F(1, 11) = 12.12$, $p = .010$, $\eta^2_p = .16$), suggesting that more prefrontal activation was detected when the WM load was high, or when the interference resolution was required ($F(1, 11) = 9.69$, $p = .021$, $\eta^2_p = .10$).

Channel 16:

The results of this channel were completely similar to those of channel 14. There was a three-way interaction of group × WM load × interference ($F(1, 11) = 24.03$, $p = .003$, $\eta^2_p = .28$). Follows-up *t*- tests revealed that HTA group showed greater activation in the interference condition with high WM load ($t(10) = 3.11$, $p = .044$, Bonfferoni-corrected), but the group differences on the other conditions were not observed (*t*s < 1.08, *p*s > .76, Bonfferoni-corrected). A main effect of group was not significant ($F(1, 11) = 2.76$, $p = .39$).

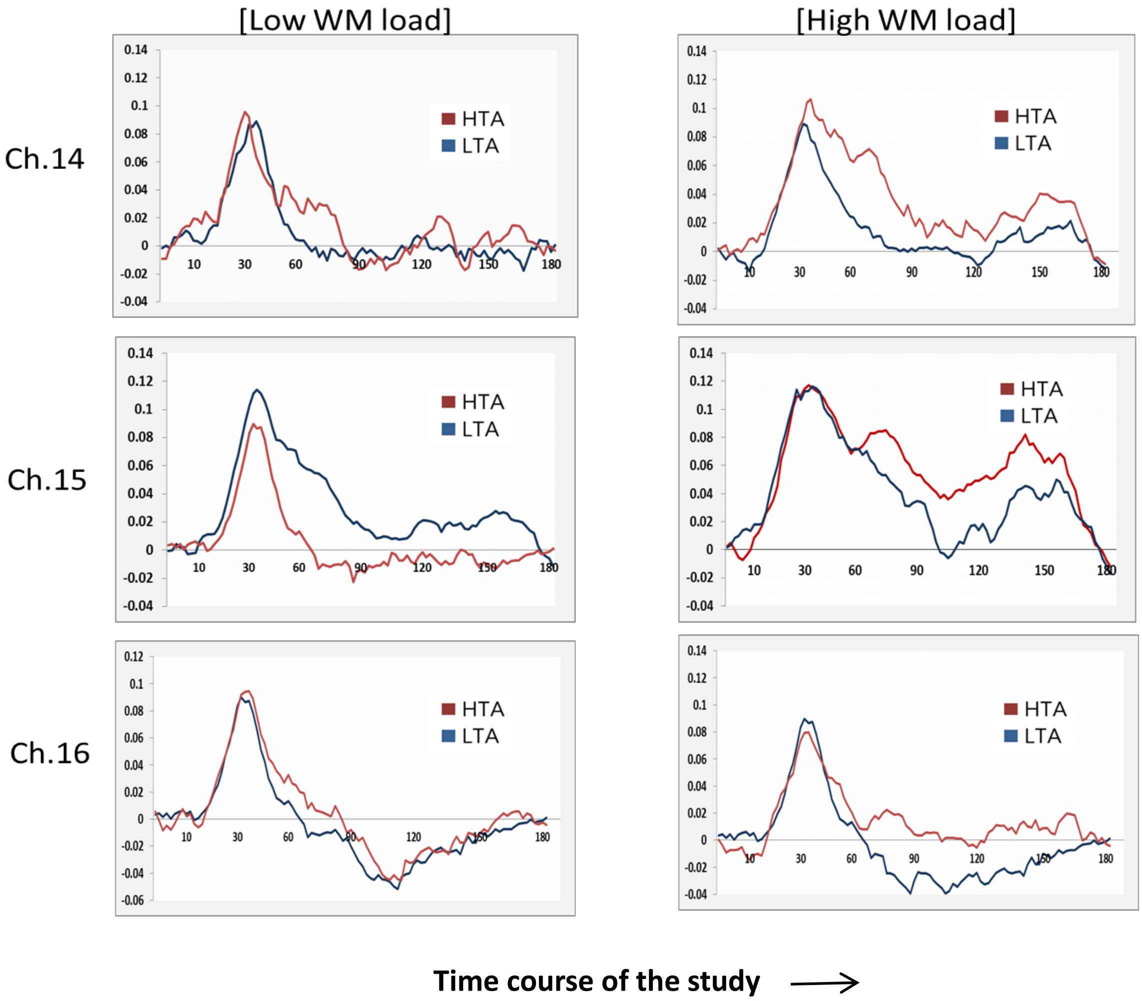

Figure 5.2 Time courses of the oxy-Hb changes in the Channels of interest under the interference condition.
WM = working memory
The vertical axis denotes relative change of oxy-Hb in mM*mm.

Discussion

In the present study, I examined the neurocognitive mechanism(s) of anxiety-related difficulty in semantic-interference resolution among representations within WM. The behavioral data indicated that semantic interference (i.e., refresh-induce inaccessibility) was successfully introduced in the block design employed for a NIRS study. More specific to our research, I demonstrated that activations in left lateral PFC subregions were differentially modulated by trait anxiety in conjunction with memory load.

There is growing evidence showing that dispositional vulnerability for anxiety can modulate the prefrontal mechanisms for top-down/executive control of attention, particularly in interference resolution (Bishop, 2007; 2009). Consistent with these findings, our results showed that differential activation patterns were observed between HTA and LTA group on channel 15 and 14/16. Of note, on channel 15 I detected the weaker activation of HTA group under interference with low WM load, and the greater activation under interference with high WM load, compared to the LTA group. This channel measures the activity in inferior part of lateral PFC, which is involved in maintenance and selection of information within WM (e.g., Fletcher & Henson, 2001). By contrast, on channel 14 and 16 HTA group showed consistent greater activation under interference in high WM load conditions. Bishop (2009) suggests that trait anxiety is associated with the decreased recruitment of prefrontal control mechanisms when attentional resources are not fully occupied by the task at hand. Our results support this claim in low WM load condition (on channel 15), but inconsistent with our results, her study did not observe the increased activation under high "perceptual" load condition. This discrepancy is supposed to be attributable to the specific effects of WM load on executive control.

It is well-established that individual differences in WM capacity reflect the ability to control attention, particularly in interfering or distracting situations (Barrouillet et al., 2004; 2007; Engle & Kane, 1999). Consequently, manipulations of WM load can occupy general cognitive resources for exerting top-down/executive processes, resulting in an enhancement of distractor/competitor interference in cognitive tasks (Lavie, 2005). A recent neurocognitive model of WM proposes that WM functions arise through the recruitment of neural circuits responsible for various attentional controls on mental representations (Chun & Johnson, 2011; Postle, 2006). Hence, the activity of lateral PFC during WM task may reflect the general executive control processes, including the flexible adjustment for internal interfering situations, as well as the temporary storage of information. Considering these proposals, increased activation of lateral PFC in high-anxious individuals should reflect the compensatory investment of brain resources for overcoming an anxiety-related difficulty in interference resolution (Eysenck et al., 2007).

Regarding the prediction from ACT about neural activity, it proposes that high-anxious individuals would show increased neural activation in prefrontal control mechanism(s) when a task places relatively high demand on cognitive control. I demonstrated that high-anxious individuals could be associated with increased neural activity in left lateral PFC when the WM load is high enough. This result straightforwardly supports the prediction of ACT. However, under low WM load, high-anxious individuals exhibited weaker activation in inferior part of lateral PFC. This result is not predictable from ACT. In light of the neurocognitive model of anxiety proposed by Bishop (2009), high levels of anxiety can be associated with decreased recruitment of lateral PCF resources in response to interference/competition resolution, when the task does not fully occupy with attentional resources. Our result of decreased activation in HTA group firmly corresponds to this claim. Taken together, these two neurocognitive models of anxiety is not mutually exclusive, rather they describe one ‘aspect’ of modulatory effects of anxiety on neural activity for top-down/executive control in conjunction with WM load. I demonstrated that anxiety is associated with regulatory alteration of attentional control mechanisms according to the level of WM load imposed on executive resources.

It should also be noted that this decreased regulation of lateral PFC was primarily associated with trait and not state anxiety or other mood states, suggesting that it reflects a processing style rather than a symptomatic outcome of altered mood states. Up here, I consistently demonstrated that trait anxiety, but not mood states, can impair executive control for interference resolution (in chapter 2, 3, and 5). Admittedly, I did not use any systematic manipulations on mood states including state anxiety. Hence, the associations of mood states and impaired control of attention were not adequately examined here. I alternatively controlled for mood states and general WM capacity properly in order to investigate the neurocognitive mechanisms of trait anxiety.

Some limitations of the present study should be noted. First, the size of our sample was rather small and preliminary. There were large individual differences in hemodynamic responses measured by NIRS. Therefore, the larger sample should be needed to extract the general pattern of brain activity in response to interference resolution within WM. Secondly, our block design did not require trial-by-trial adjustment of attentional control, rather it needed monotonous control for resolving a semantic interference (in the interference block). Recently, Osinsky et al (2012) suggests that trait anxiety can be associated with the tendency to anticipatory allocation of attentional resources to potential target of subsequent processing. They demonstrated that following a processing of conflict, high trait-anxious individuals would allocate more attentional resources to the processing of task-relevant information, concurrently withdrawal of attentional resources from processing of task-irrelevant information. Thus, it is highly important to set unpredictability of requirement for attentional control in order to examine the association of anxiety with trail-by-trail adjustment of attentional control more suitably (Bishop, 2009; Braverman & Meiran, 2014). Lastly, although the NIRS sensor covers lateral PFC widely (SFG, MFG, and IFG), it does not cover rostral area of PFC such as premotor cortex, which implicates attentional focus shifting. Selective refreshing may involve shifting process from one item currently in the focus of attention to another being out of focus. Further researches are needed to clarify the more elementary executive processes on which anxiety can affect at behavioral and neural levels.

Chapter 6

Conclusion

Across four studies, I examined the behavioral and neural processes underlying anxiety-related difficulty in interference/competition resolution. Specifically, I focused exclusively on the impact of trait anxiety on executive control for interference/competition resolution among mental representations in WM. The prominent framework of this research area, ACT posits that anxiety disrupts inhibitory control implemented in executive component of WM (Berggren & Derakshan, 2013; Eysenck et al., 2007). Therefore, I examined the association(s) of trait anxiety and sub-processes of inhibition acting on mental representations, namely, competition resolution, distractor resistance, and intrusion resistance (Friedman & Miyake, 2004; Nee at al., 2007) were considered.

Behavioral evidence of anxiety-related difficulty in executive control on working memory

In chapter 2, I first demonstrated that high-anxiety individuals exhibited larger semantic interference (i.e., refresh-induced inaccessibility; Higgins & Johnson, 2009), suggesting that the magnitude of this interference effect was modulated by trait anxiety level (Hoshino & Tanno, in press). I consider this anxiety-related difficulty in interference resolution in WM as one of the elementary processes arising uncontrollability of anxious apprehension or worry that is a characteristic of pathological anxiety (Derryberry & Reed, 1997; Stout et al., 2014). Some studies show that trait anxiety disrupts gating and filtering functions of WM, implying that irrelevant information can easily get access to WM in high-anxious individuals (Stout et al., 2013; 2014; Qi et al., 2014). Taking these findings into account, high-anxious individuals experience uncontrollability of worry due to their difficulty excluding irrelevant or unwanted information from WM, which would result in the development of the thought process of worry. Moreover, their difficulty of cognitive control in the process of selectively directing reflective attention from the current thought to another semantically similar thought might maintain the current stream of worrisome thought.

By neuroimaging studies, the neural bases of selective refreshing were shown to be mapped on the left lateral PFC including IFG and MFG (Johnson et al., 2005; Ray et al., 2007; 2008). These regions overlap with the cortical regions in which anxiety-related regulatory alterations have been reported in previous studies (e.g., Ansari & Derakshan, 2011; Basten et al., 2011; Bishop, 2007; 2009). Although opposite activation patterns on these regions (greater or weaker activation in relation to anxiety) were observed according to the circumstances, it is highly consistent across studies that trait anxiety has close ties to regulatory alteration of executive control mechanisms in lateral PFC.

We further investigated this issue by systematically manipulating WM load (Vytal et al., 2012) of the selective refreshing task in combination with prefrontal hemodynamic responses assessed by NIRS.

I also demonstrated that anxiety can disrupt distractor-resistant WM in the face of dual-task interference in chapter 3. Dual-task interference in WM is thought to depend heavily on attentional control and memory selection (Barrouillet et al., 2004; 2007; Wager, Spice, Insler, & Smith, 2014). Therefore, we employed the complex span paradigm which is designed to manipulate the temporal factor for re-activating WM contents by competing attentional resources with simple processing task (Barrouillet et al., 2004; 2007). Performance on this paradigm is assumed to depend on the efficiency of attentional control to re-activate and prolong (i.e., refreshing) the decaying memory traces in between each distractor processing, not necessarily the phonological rehearsal. I showed steeper decline of memory performance in HTA group, suggesting that high-anxious individuals have difficulty in resisting distractor interference on WM as the time constraint on refreshing memory traces becomes more severe.

Taken together, these findings certainly indicate that anxiety can exert homogeneous effects on attention control acting on mental (internal) representations as visual/perceptual processing. Even so, however, not all sort of executive control on mental representation is associated with the levels of trait anxiety, as seen in chapter 4.

The lateral PFC regions have been considered to be the core mechanism implementing distractor resistance in WM, particularly in dual-task interference (Nee et al., 2012; Sakai, Rowe, & Passingham, 2002). However, a recent study challenged this view, demonstrating that WM performance under dual-task interference was substantially predicted by activity in the presupplementary motor area that implicates dual-task coordination (Wager et al., 2014). They also showed that activations in lateral PFC regions predicted WM performance irrespective of dual-task interference, suggesting that the role of these cortical regions is specifically involved in the maintenance of representations in WM. Considering these findings, our results obtained in chapter 3 can be re-interpreted as the manifestation of anxiety-related difficulty in dual-task coordination (or task-switching; Ansai, Derakshan, & Richards, 2008), not necessarily the lateral-PFC-centered function of distractor resistance. In light of this speculation, anxiety can affect attentional control regions other than executive control mechanisms centered in lateral PFC. Further researches are required to elucidate the impacts of anxiety on brain regions according to task demands and type of interference in more detail.

Neural basis of anxiety-related regulatory alteration of executive control on working memory

By employing the selective refreshing task with high and low WM load, I demonstrated that high-anxious individuals consistently exhibited greater activations across left lateral PFC under high WM load. By contrast, they showed weaker (but significant) activation only in inferior part of IFG under low WM load. This pattern of results suggests that activities in subregions of left lateral PFC are differentially modulated by trait anxiety in conjunction with WM load (or available attentional resources).

In a former case, high WM load should consume attentional resources and disrupt cognitive operation for controlling over semantic interference both in HTA and LTA groups. Therefore, it is plausible that participants in both groups equally needed to take some strategies to overcome the interference. In contrast, hemodynamic responses assessed by NIRS indicate that high-anxious individuals invested more 'effort' to perform the task, compared to those low in anxiety. That is, the wide-spread activation of lateral PFC reflects the processing style of HTA group for compensatory cognitive attempts which they habitually utilize (Berggren & Derakshan, 2013; Eysenck et al., 2007).

I observed weaker activation of HTA group in inferior part of left lateral PFC under low WM load. This result is consistent with Bishop (2009), indicating the anxiety-related decreased recruitment of prefrontal resources in anxiety when the attentional resources are not fully occupied with the task at hand (see also Vytal et al., 2012). In such a case, task-irrelevant verbal activity such as apprehension or worry is supposed to compete with attentional resources, resulting in performance decrement (Eysenck & Calvo, 1992; Sarrason, 1986; Vytal et al., 2012). On the other hand, semantic interference built in the selective refreshing task was difficult to become aware explicitly under low WM load, because the task itself was rather easy to perform (performance accuracies were over 99%). Therefore, unlike the high WM load condition, participants seemed not to rely on cognitive strategies spontaneously. From these, I interpret this weaker activation of HTA group as the manifestation of anxiety-related difficulty in regulating the activity of executive control region at optimal levels when needed.

Translation into the cognitive symptomatology of anxiety

All through the researches here, I investigated the association of anxiety with interference control in WM. Because high-anxious individuals experience excessive and uncontrollable worry regardless of current context, I explored the neurocognitive mechanisms of memory selection (refreshing), memory maintenance (distractor resistance), and memory intrusion (intrusion resistance) in WM. From the results of chapter 2, and 5, high-anxious individuals are proven to be particularly vulnerable to semantic interference when selecting a representation in WM. Moreover, the regulatory alteration of executive control mechanisms in left lateral PFC underlies this difficulty in cognitive control. Interestingly, this anxiety-related regulatory alteration varies according to task demands. In consideration this, I hope that effective approaches for treating maladaptive cognition of anxiety will be developed.

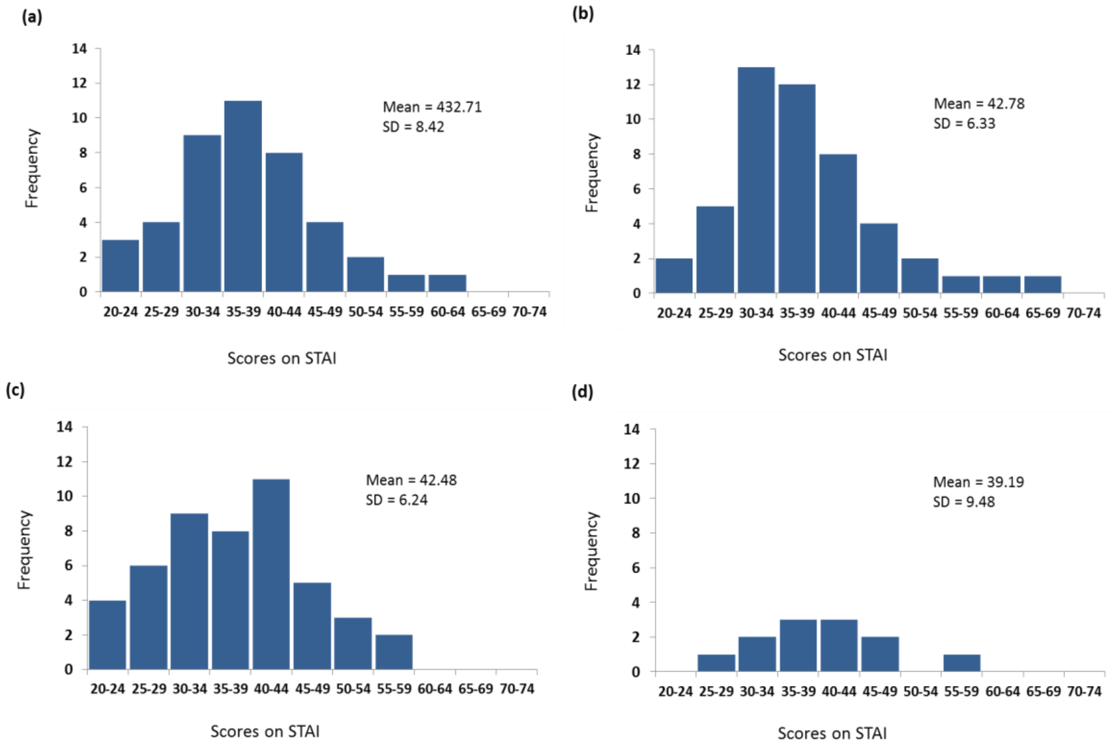

Figure A. Distributions of scores on STAI
Panel (a) represents the distribution of scores on STAI in the study appeared on Chapter 2. Likewise, Panel (b) , (c), and (d) are the histograms of STAI scores conducted in the study of Chapter 3, 4, and 5, respectively.

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