SELECTIVE ATTENTION UNDER DIFFERENT PRESSURE SOURCES AND PERCEPTUAL LOADS

BY

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ABSTRACT

Using a flanker task paradigm, a series of four experiments were conducted to investigate how selective attention under different perceptual loads is affected by pressure. The first three experiments examined the pressure effects on selective attention of non-emotional stimuli (i.e., letters), and the fourth experiment investigated the same using emotional stimuli (i.e., emoticons). In Experiment 1, using a "fixational" flanker task and perceptual load manipulation, it was found that under pressure, the flanker effect was increased under high load for the outcome pressure group. In Experiment 2, the "fixational" flanker from Experiment 1 was moved to the periphery to see whether distractor location matters, and the pressure effects for the outcome pressure group were replicated. Experiment 3 investigated how distractor relevance would interact with the pressure effects by introducing an attentional capture task to Experiment 2's design. The findings for the flanker effect from Experiment 2 were replicated, and it was further found that distraction from task-irrelevant stimuli was not affected by outcome pressure. Experiment 4 made use of emotional stimuli (i.e., sad emoticons versus happy emoticons), but no pressure effects were found either for the flanker interference effect or for the attentional capture effect. From these results it can be concluded that high outcome pressure disrupts cognitive control for non-emotional task-relevant stimuli such as letters, but does not affect control for emotional stimuli such as emoticons.

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CHAPTER 1 INTRODUCTION

"Choking under pressure" is defined as subpar performance that occurs when the importance of performing well is higher than usual or over-emphasized (Baumeister, 1984). For example, top professional athletes sometimes perform worse than their usual abilities allow when competing at the Olympic Games because of the high-stakes of this competition. A well-qualified job candidate may flunk an interview answering technical questions to which he/she would ordinarily know the answers to, simply because of the pressure surrounding the interview itself. And in education, it is often observed that students who are expected to overachieve in high-stakes standardized tests like the SAT and the GRE, end up performing below their potential. Scientific study of the "choking-under-pressure" phenomenon has taken off significantly over the past decade, thanks in large part to research by Beilock and colleagues (Beilock & Carr, 2001; Beilock & Carr, 2005; DeCaro et al, 2011).

1.1 Theories of choking under pressure

Why would people "choke" despite striving for superior performance? Studies have been conducted to reveal the answers to this question, and two classes of theories have been proposed to explain "choking under pressure".

Distraction Theory

The first theory of choking under pressure is called distraction theory. It claims that under pressure, attention is divided between the task at hand and task-irrelevant worries and thoughts (Wine, 1971; Beilock & Carr, 2001). Distraction theory was developed from test-anxiety theory, which argued that for highly test-anxious individuals, self-relevant variables and task-relevant variables were both competing for attentional resources (see Wine (1971) for details about test-anxiety theory). Examples of self-relevant variables for an individual include worries about his or her own performance, worries about how well others might perform, and repetitive ruminations over different possibilities when attempting to solve problems (Wine, 1971). Distraction theory extended test-anxiety theory to much broader areas, and is applicable to any pressure situation in which focused attention and working memory are required to finish the task. Under pressure, individuals are put in a situation of “maladaptive multi-tasking” (i.e., thinking about too many things at once: “Will I win? What if I miss this shot? All my teammates are watching!”). Pressure-related thoughts and worries overwhelm our attentional system and it is this form of cognitive multi-tasking that causes people to under-perform (Beilock, 2008).

According to distraction theory, complex cognitive tasks that rely heavily on working memory and focused attention should be impaired by pressure situations. This hypothesis is supported by several studies using math problem solving tasks (Beilock & Carr, 2005; Beilock & Decaro, 2007) and categorization tasks (Markman, Maddox, & Worthy, 2006). For example, Beilock and Carr (2005) used math problem solving tasks and investigated how pressure would interact with working memory capacity to compromise math performance. The math tasks they created were modular arithmetic ones in which participants were told to judge the truth value of equations. An example of one such math problem is $46 \equiv 21 \pmod 6$. To do this problem, participants must first subtract 21 from 46 (which is 25), hold this answer in working memory, and then divide it by 6. Since 25 cannot be evenly divided by 6 without a remainder, the answer should be “false”. The difficulty of math problems was also manipulated by varying the level of dependence on working memory required to solve the problems. Results showed that easy math problems that do not heavily rely on working memory are not affected by pressure manipulation, whereas difficult math problems that require demanding computations in working memory are solved less accurately under high pressure. In addition, this degraded performance under high pressure only happens to those with high working memory capacity. For those individuals with low working memory capacity, it seems that performance is not affected by pressure manipulation due to a floor effect.

Markman et al (2006) adopted two kinds of categorization tasks in their study: rule-based categorization tasks and information-integration categorization tasks. For rule-based tasks, one must figure out an easily verbalizable rule to categorize objects into two groups (e.g., items with a specific feature belong to category A). For information-integration tasks, one must integrate multiple stimulus dimensions at a pre-decisional stage (i.e., accumulating stimulus-response associations). Rule-based tasks are typically thought to involve explicit hypothesis testing and thus are dependent on working memory, whereas information-integration categorization tasks, according to the authors, do not place great demands on working memory. Information-integration categorization tasks are thought to be best learned via a procedural or similarity-based process, which is implicit. According to distraction theory then, pressure will impair rule-based categorization tasks, but not information-integration tasks. And this is exactly what they found in their study.

It can be noted that even though distraction theory talks about how attention is distracted, these studies mostly use working memory intensive tasks rather than attention tasks. On the one hand, attention and working memory are closely related to each other (e.g. Baddeley, 2000; Cowan, 1995; 1999; Engle, 2002). However, there is no study directly testing basic attention effects under pressure.

Monitoring Theory

The second theory of choking under pressure is called explicit monitoring theory (Baumeister, 1984; Lewis & Linder, 1997). It proposes that pressure increases self-consciousness and anxiety about success and increases attention to the execution of skilled performance, which in turn disrupts that performance. Support for this theory comes from studies of sensorimotor tasks that become proceduralized with practice -- that is, skills that are usually performed without constant executive monitoring (Beilock & Carr, 2001; Gray, 2004; Liao & Masters, 2002).

For example, Beilock & Carr (2001) used a laboratory golf putting task and trained undergraduate participants without golf putting experience in three conditions: single task, distraction, and self-consciousness. In single-task training, participants were trained on the golf putting task. In distraction training, a secondary auditory monitoring task was introduced to the golf putting training. In self-consciousness training, participants were told that they would be video-taped so that golf teachers and coaches could review and get some understanding of how individuals learned golf putting. After the training session, participants were tested in a single golf putting task under both low pressure and high pressure conditions. If pressure creates distraction in the golf putting task, then the distraction training group should benefit from their training environment most and thus their performance would improve in the high-pressure test session. However, if pressure increases self-consciousness, then the self-conscious group should benefit most from their training environment. Results supported the latter hypothesis. While the logic of this study is somewhat indirect, it does provide support for explicit monitoring theory.

Relatively more direct evidence comes from Gray (2004). In this study, expert baseball players were tested in a simulated baseball batting task. In addition, a secondary judgment task was added to randomly-selected trials. The secondary judgment task, prompted by a tone during the swing and completed after the swing was finished, was either to judge the frequency of the tone itself or judge the movement of the bat when the tone appeared. Results showed that in high-pressure situations, expert baseball players batting performance decreased, compared to low-pressure situations. However, the decline in batting performance was accompanied by an improvement in judging the batting movement. These findings suggest that under pressure, expert baseball players focused more on their skills during skill execution, which disrupted their proceduralized batting processes.

Summary

These two “choking under pressure” theories differ in the role and emphasis that they place on attention. With distraction theory, it is argued that attention is diverted away from the main task and is partly occupied by irrelevant thoughts or worries induced by the pressure situation. In contrast, explicit monitoring theory argues that under pressure, we “over-monitor” performance of skills that we have perfected and that are usually executed smoothly without close monitoring. For instance, basketball players may not need to monitor the exact location of their shoulder, elbow, and wrists while shooting a free-throw. They just shoot it. But, under pressure, they may become preoccupied with the exact location of these joints, and therefore, this over-monitoring can interfere with the execution of an otherwise smooth movement. Though these two theories appear to contradict each other at first, they actually complement each other, as they are aimed at describing the effects of pressure in two different types of domains: unautomated cognitive tasks (like math testing) versus proceduralized tasks (like golf putting) and automated (through practice) cognitive tasks.

DeCaro et al. (2011), however, argued that it would seem strange that the identity of the object one is holding, whether “a pencil or a baseball bat”, would moderate the effect that high pressure has on attention. They suggested that perhaps researchers should start focusing in more on the “pressure situation” itself.

1.2 The pressure manipulations and pressure sources

There are two categories of pressure situations depending on whether or not the pressure source directly correlates with the task at hand. For example, students who are about to take the GRE test could be in a high pressure situation in which the pressure source comes from the worries and anxieties of getting a good score. And in this case, the pressure source is directly related to the task. On the other hand, if these same stressed out students, feeling the pressure from their impending GRE tests, were invited to a psychology lab to do some attentional tasks, then the attentional tasks themselves would be uncorrelated with their pressure source. The terms “pressure” and “stress” are both used in the literatures on how high pressure or high stress situations can affect performance. However, literatures using “pressure” or “stress” rarely overlap.

In most literatures for “choking under pressure”, the pressure situation is created by a social psychological method. A cover story is constructed to make participants believe it is true and to create a pressure situation (e.g., Beilock & Carr, 2005; Beilock & DeCaro, 2007; Gray, 2004; Hardy et al 1996). In one cover story, the participant in the pressure group is told that he/she will earn extra money if he/she can improve their performance in the second half of the experiment and that this is an exercise in team work (i.e., he/she has been randomly paired with a partner). Both participants have to achieve a pre-specified improvement rate in order to get the extra bonus. The participant is told that his or her partner has already achieved the necessary improvement; therefore, the responsibility for both "participants" receiving the extra bonus lies solely on the participant under pressure. In addition, he/she is told that the second part of the experiment will be video-taped. The pressure situation created by this cover story contains several components. DeCaro et al (2011) differentiated two pressure sources in high-pressure situations created by the above cover story: monitoring pressure and outcome pressure. Monitoring pressure refers to the pressure that is induced by being watched by others (i.e., watched by a teacher, audience, or video camera), and outcome pressure refers to the pressure induced by outcome incentives (i.e., scholarship, monetary reward, high test score, etc.). Social psychology studies have shown that the presence of a mirror, an audience, or a video camera increases self-consciousness or self-awareness (Carver & Scheier, 1978; Geller & Shaver, 1976). In this sense, monitoring pressure would probably make attention more focused on the processes and procedures during task performance. In contrast, outcome pressure may distract the focus of attention to the pressure situation and its consequences (DeCaro et al, 2011).

Supporting evidence for the different effects of the two pressure sources comes from Markman et al (2006) and DeCaro et al. (2011). Markman et al (2006) only manipulated outcome pressure in their study, and compared to the low-pressure situation, they found that the high-pressure situation impaired performance on a rule-based category learning task, but enhanced performance on an information-integration task. DeCaro et al. (2011) further investigated the interaction between the effects of the two pressure sources on these two types of categorization tasks. They found that pressure induced by outcomes produced distraction and hurt rule-based category learning performance, while performance on the information-integration task was unaffected by outcome pressure. In contrast, the opposite pattern was found for the monitoring pressure manipulation – performance on the information-integration categorization task was degraded, but performance on the rule-based task was not.

On the other hand, for literatures using the term “stress”, the main focus is on how stressful situations disrupt cognitive control or executive control in general.

Liston et al. (2006, 2009) investigated the neurobiological basis for “chronic stress”. They did studies on both rats (Liston et al., 2006) and college students (Liston, McEwen, & Casey, 2009). The study on rats showed that 21 days of repeated restraint stress reduced dendritic arborization and spine density in the medial prefrontal cortex. These stress-related structural changes led to significant impairment of attentional-set-shifting (or task-set-switching). Comparable changes were also found in humans. Psychosocial stress impaired attentional control and disrupted functional connectivity within a fronto-parietal network that mediates task switching.

However, the “psychosocial stress” in these studies is slightly different from the “pressure” discussed above. For example, the stress in Liston et al (2009) differed from the pressure elicited in the studies mentioned above in two important ways. First, the stress of participants had nothing to do with the task they performed in the lab. Participants in the stress group in Liston et al (2009) were medical students preparing for a medical licensing examination, which was a major examination for them and was perceived to be highly stressful for a period of weeks. For the pressure studies, the pressure situation was directly related to the task participants were performing. Second, the stressful situation in Liston et al. (2006, 2009) was a relatively long-term state, whereas for the pressure studies mentioned above, the pressure only happened while participants were doing the experiment. Compared to chronic stress, it would also be very interesting to see how short-tem performance pressure, especially when it is directly related to the task itself, would affect task switching.

1.3 Performance pressure and attention

Both distraction theory and explicit monitoring theory focus on how pressure affects the allocation of attention, and both place attention at the center of the interference effect of pressure on performance. In spite of the important role of attention in these theories, no study has directly tested whether the basic cognitive mechanism of attention actually works differently under pressure. It is assumed that this is the cause of the problem; yet, this basic assumption remains untested. For instance, studies focused on distraction theory have used performance in math tasks, problem-solving tasks, and category-learning tasks as dependent variables. Never have they directly used tasks designed to *only* measure attention, such as endogenous cuing, attentional capture, and attentional selection. This comes as a surprise, because the overall theory is that attention and executive control play an important role in pressure effects. Thus, it is imperative to test them directly.

In the attention field, different theories have been proposed to explain how attention works in the face of distraction. The work of Lavie and colleagues has been most influential in that regard. Lavie et al (2004) proposed a "load" theory of attention and cognitive control. There are two ways in which to influence the degree to which we select – that is, "pick" – which information we pay close attention to and which gets disregarded.

First, there is a perceptual selection mechanism, that is affected by the complexity (or load) of perceptual information. When perceptual information is easy to process (low perceptual load), there is enough capacity in the system to process irrelevant or distracting information, and thus, this happens automatically without much effort. When perceptual information is hard to process (high perceptual load), all the system's capacity is focused on processing small bits of the world at a time (e.g., trying to find Waldo in a "Where's Waldo" illustration), and little to no irrelevant information gets processed deeply by the brain. Perceptual load is usually manipulated by changing the number of items or set sizes relevant for target perception (Lavie, 1995), or by varying the perceptual processing requirements for the same items. For example, increasing the similarity between the targets and nontargets or using a complex discrimination of feature conjunction rather than a simple presence detection would create high perceptual load (Lavie & Cox, 1997).

In addition, there is a second control mechanism that is not automatic but is under our control, and it is in charge of actively rejecting or blocking irrelevant information that may have made it past the first (perceptual) selection stage. This control mechanism is important only under conditions of low perceptual load when spare capacity ends up processing irrelevant information. This attention control mechanism is a more central cognitive mechanism, directly linked to our "executive control center" – that is, the mechanism that "knows and controls" all the things we should be thinking about. For instance, if we are trying to look for our car keys while trying to remember an address, our executive control system juggles the control of both tasks so that we can succeed at both simultaneously. According to Lavie, in situations of low cognitive load (i.e., there are no other demands on our executive system other than the task at hand), we have the capability to use this attentional filter to block distraction. In contrast, in situations of high cognitive load (i.e., when our mind is occupied by other concurrent tasks), we fail to control our attentional filter and irrelevant information that makes it past the perceptual filter also passes this control stage. In this case, distractors become fully processed and can seriously impact our behavior.

Cognitive load is usually manipulated by adding a second task to the participant's main task. For example, in addition to having to find a target in a cluttered display, participants are also asked to remember some important information during the search. The "cognitive load" can therefore be easily manipulated via methods such as increasing the number of items to remember (Lavie et al, 2004).

In sum, increasing perceptual load (or perceptual complexity) will reduce distractor interference, whereas increasing cognitive load will increase distractor interference. A natural question arises from this framework: How does pressure relate to perceptual and cognitive load?

Pressure could possibly create tunnel vision and reduce the size of the useful field of view. Hockey (1970a; 1970b) found that stressors such as loud noise can interfere with selective attention to peripheral targets. Specifically, under a loud noise condition (high stress condition), he found that peripheral signals were detected less often compared to a no noise condition (low stress condition). However, the detection of central signals was improved under the loud noise condition. These results suggest that high stress reduces the attentional window to a central area. Belopolsky et al (2007) also showed that the size of attentional window determines whether some irrelevant information gets processed in the same way.

However, tunnel vision and attentional window reduction have different predictions when the distractor is at the periphery vs. at fixation. By reducing the amount of information to get processed in the first place, pressure (under some conditions) might have effects similar to those of perceptual load. This is likely to be especially true when the distractor is at the periphery and there is a reduction in the amount of attentional resources available to process peripheral distractor information. In other words, we would expect that under high-pressure conditions, there are not enough resources left for processing perceptual distractors in the periphery, and therefore, the interference from external distractors on performance will be reduced). When the distractor is at fixation, tunnel vision probably would either not affect distractor processing much or even further enhance the distractor processing. On the other hand, pressure may work as a form of cognitive load. If this is the case, one would expect to see that in pressure situations, one becomes particularly vulnerable to distractions from the world, as the second attentional filter is unable to filter out distractions that, under normal conditions, one would not process. It could then be concluded that pressure opens a gate to distraction and it is because of this, that performance falters.

A recent study by Sato, Takenake, and Kawahara (2012) used a flanker task and examined how "acute stress" and perceptual load may interact with each other on selective attention. In a standard Flanker task (Eriksen & Eriksen, 1974), participants respond to a target (e.g., letters, shapes, colors, etc.) by pressing one of two response keys. The target is surrounded by distracting items (or flankers) that could be either the same as the target (compatible trials), perceptually different from the target and refer to an opposite response as the target (incompatible trials), or perceptually different from the target but do not refer to any response (neutral trials).The typical finding for a flanker task is that the reaction times (RTs) in compatible trials are the fastest, followed by neutral trials, and then by incompatible trials. This pattern of results demonstrates a failure of selective attention and is referred to as the flanker effect.

The flanker task in Sato et al (2012) was to search for a letter (i.e., N or Z) in one of the three columns, with non-target letter Xs on the center area, and with exactly the same two flankers (N or Z) on the periphery. Perceptual load was manipulated by changing the set sizes of the center columns, and acute stress was induced by asking the participants to deliver a 5-minute speech about their own weaknesses and strengths in front of a video camera. Results showed that the high acute stress situation reversed the load effect on flanker interference. Specifically, instead of showing a larger flanker effect under low load and a smaller flanker effect under high load as one would expect to see in a normal situation, participants under high acute stress revealed a larger flanker effect under high load, and the flanker effect under low load was almost eliminated. The authors of the study concluded that these results indicated that perceptual load and stress shared common attentional resources. However, the fact that the high acute stress situation created the increased flanker effect under high load and eliminated the flanker effect under low load could not be well incorporated into the current load theory. In order to explain the opposite pattern of results found, they proposed an account of "excessive load". According to this account, the combination of high perceptual load and high stress would create an excessive load, which would impair the maintenance of the task set. Under this excessive load, an optimal task set for selectively focusing on the target location and filtering out the flanking distracters becomes fragile.

Given the fact that high acute stress, which is not directly related to the flanker task at hand, produces the opposite pattern of the perceptual load effect, a natural follow-up question to ask is whether outcome pressure, which is directly related to the task at hand, affects selective attention under load in the same way. Addressing this question will also serve as a good start to try to discuss both pressure and stress in the same framework as well.

CHAPTER 2 OVERVIEW OF THE PRESENT STUDY

The goal of this dissertation was to investigate how selective attention under different perceptual loads is affected by different pressure sources. The two pressure sources examined were outcome pressure and acute stress. However, in the series of studies that were conducted, the acute stress manipulation did not seem to work. Thus, it was decided that the acute stress data would be removed from the final dissertation write-up.

The flanker response-competition task was used as a measurement for selective attention (Eriksen & Eriksen, 1974). Instead of using different set sizes to manipulate perceptual load (Sato et al, 2012), the same flanker task used in Beck and Lavie (2005) was adopted in which perceptual load is manipulated by varying the perceptual complexity of the search displays. We will examine whether we could replicate the findings of Sato et al. (2008) by using different perceptual load manipulations. In addition, one advantage of using the same set size while changing the display complexity to manipulate perceptual load is that this avoids any possible concerns raised by dilution theory (Tsal & Benoni, 2010). Tsal and Benoni (2010) argued that changing the set sizes confounds the experiment design, due to a degree of dilution created by the non-target letters. According to load theory by Lavie and Tsal (1994), the reduced flanker effect under high perceptual load is due to the fact that more attentional resources are taken by the search displays and thus little available resources are left to process the distractor or flanker. According to dilution theory, however, there are also more non-target letters under high perceptual load (using set size manipulations). Therefore, the interference effect from the distractor (or the flanker) would be diluted, and thus lead to a reduced flanker effect compared to that under low load. In order to avoid this important confounding effect that is caused by varying set sizes, it was decided to go with the better perceptual load manipulations adopted by Beck &

Lavie (2005). This more or less rules out any possible dilution difference between high load and low load displays.

Also of interest, is how the outcome pressure and acute stress differ from one another. Therefore, both outcome pressure and acute stress manipulations were originally included in the study. However, since the acute stress manipulations never worked in the conducted experiments, the acute stress group was abandoned in reporting, in order to reduce the amount of noise in the data and increase the power of ensuing statistical analyses. The same outcome pressure manipulations used by DeCaro et al. (2011) were followed, in which the high-pressure situation was mainly created by monetary rewards along with some social concerns such as team work. As in Sato et al. (2012), participants' STAI-state was also measured both at the beginning and at the end of the experiments. STAI is a self-report instrument to measure state and trait anxiety in adults (Spielberger, 1976). State anxiety refers to an individual's transitory experience of tension, nervousness, and worry, whereas trait anxiety refers to an individual's relatively stable anxiety and is supposed to be a personality trait. STAI has been shown to be valid and reliable, and is widely used in many studies (Fountoulakis et al., 2006). In the following studies, the STAI-state scale was only used to measure participants' current emotional state as an index of pressure level. The STAI-state scale consists of 20 statements that evaluate how participants feel "right now, at this moment". Examples of those statements are "I feel calm", "I am tense", and "I feel frightened", etc. Each statement is rated on a four-point intensity scale and the total score indicates the anxiety level of the individual, with higher scores meaning higher anxiety levels. In this study, the STAI-state was used as a validity check to see whether the pressure manipulations had any effect on participants. Note that the STAI-state scale is not a direct measure of pressure.

However, as shown in Sato et al (2012), increased levels of pressure are likely accompanied by increased anxiety.

This dissertation consists of four experiments. Experiment 1 investigated how pressure manipulations affect selective attention under different perceptual loads when the distractor (or flanker) is centrally located. Experiment 2 investigated whether the location of the distractor affects the interaction between pressure effects and flanker effects under load. Experiment 3 manipulated the task-relevance of distractors and addressed the issue of whether a bottom-up task-irrelevant distractor is different from a top-down task-relevant distractor in terms of selective attention under load, and whether different pressure levels affect them differently. Together, Experiments 1 to 3 investigated selective attention under load and pressure for neutral stimuli (i.e., letters). In contrast, Experiment 4 examined whether pressure affects selective attention for emotional stimuli (i.e., emoticons). Happy, sad, and neutral faces were used as stimuli for the search task and the interference effects from the bottom-up task-irrelevant distractors vs. top-down task-relevant distracters were compared. Most importantly, the Experiment investigated how the interference effect changes as a function of pressure levels and target emotional valence.

CHAPTER 3 EXPERIMENTS

3.1 Experiment 1: Effects of Perceptual load and Pressure on selective attention

Using a flanker task, Experiment 1 investigated how high versus low perceptual load affects selective attention, and how different pressure levels modulate these effects.

In this experiment, the “fixation distractor” display from Beck and Lavie (2005) was adopted. The task is to search for a target letter X or N in an imaginary circle composed of six letters, including the target letter and five other non-target letters. In addition, a center distractor (or flanker, which could be either X or N) was present in the interior of the circle. As Figure 1 shows, perceptual load was manipulated by varying the display complexity using either homogeneous non-target letters or heterogeneous non-target letters.

Results from Beck and Lavie (2005) showed that the flanker effect was larger under low perceptual load than under high perceptual load. According to Sato et al (2012), if high pressure and high perceptual load creates an excessive load which will disrupt maintenance of the task set, then we would expect to find an increased flanker effect under the combination of high pressure and high perceptual load. Alternatively, if perceptual load is purely determined by display factors such as set size or display complexity, and the reduced flanker effect under high perceptual load in a normal situation is due to the fact that the searching task itself occupies more of the limited attentional resource, then one would not expect pressure to impact the flanker effect in the high load condition. According to perceptual load theory and the distraction theory of choking under pressure, however, high pressure should impact the flanker effect in the low load condition. Specifically, we would expect to see a reduced or eliminated flanker effect in the condition of low perceptual load and high pressure.

Method

Participants

Forty naïve participants (23 female; age range, 18-32 years) were recruited from the University of Illinois at Urbana-Champaign through online advertisements. All of the participants had normal color vision and either normal or corrected-to-normal visual acuity. They all got paid $10 for their participation, with participants in the outcome pressure group receiving an extra $10 for a total of $20 (which was part of the pressure manipulation).

Stimuli and Apparatus

All stimuli and conditions were generated by a series of computer programs written in MATLAB using the psychophysics toolbox (Brainard, 1997; Pelli, 1997). The programs were run on a 3.4 GHz Pentium IV PC and stimuli were presented on a 20-inch CRT monitor at a resolution of 1024×768. The programs recorded all relevant key-press responses and response times. The viewing distance was 50cm and was stabilized by a chinrest to make sure the distance was constant across the whole experiment and participants. All stimuli were presented in a light gray color ([180,180,180]) on a black background ([0,0,0]). Each trial consisted of a dot fixation on the center, which subtended 0.23 degrees of visual angle and a search display with letters. The search display consisted of six possible non-target letters [S,K,V,J,R,O], one target letter (X or N), and one distractor letter (X or N). All letters were of the font type "Arial". The target letter and non-target letters subtended 0.54 degrees vertically. The distractor letter, always located in the center, was 1.3 times larger (0.67 degrees vertically) than all the other letters. All target letter and non-target letters were positioned in an imaginary circle with a radius of 2 degrees.

Design and Procedure

A mixed design was used by having load × compatibility (2 × 2) as within-subjects factors and the pressure manipulation (control, outcome pressure, and acute stress) as a between-subjects factor. Each trial consisted of the following sequence. A fixation dot was displayed on the center of the screen for 2000ms, followed by a search display with letters for only 200ms. Participants were asked to search for a letter X or N in the circle while ignoring the relatively larger letter on the center. They were required to press the left-arrow key for X and right-arrow key for N using their left and right index fingers, respectively.

As Figure 1 shows, there were four conditions. For the low perceptual load conditions, non-target letters were always Os and the distractor (always located in the center) was either an X or N. For the high perceptual load conditions, non-target letters were [S,K,V,J,R]. When the distractor was the same as the target letter, it was a compatible trial. When the distractor and target were different letters, then it was an incompatible trial. There were 480 trials total and trials from different conditions were mixed together. Given that this was a very demanding task, participants went through a practice session with 96 trials at the beginning of the experiment, followed by two blocks which were referred to as pretest and posttest later in the data analysis section. The second block was an exact repetition of the first block, except that the trial order within each block was randomized.

There were two groups: the control group and the outcome-pressure group. Each group had 20 participants who were paid for their participation. In the beginning of the experiment, they were asked to complete the STAI-state (i.e., the state-anxiety scale in the State-Trait Anxiety Inventory) to measure their baseline state anxiety. At the end of the experiment, they were asked to complete the STAI-state again to measure their anxiety level post test, and as well as Post-experiment Pressure Questionnaires in which they report how pressured they felt in the second half of the experiment.

In the control group, participants completed the first block, took a break for four or five minutes, and then completed the second block.

In the outcome pressure group, after participants completed the first block, they were told that they had an opportunity to double their payment if they and a partner could both improve their performance by 20% in the second block. They were told there was an algorithm to calculate a score based on their accuracy and reaction time, and that their partner had already successfully improved their own performance (so all responsibility lay with the participant). However, none of this story was actually true. There was never any partner, and participants in this group always earned twice the advertised money no matter whether they improved their second block performance by 20% or not.

Results

Participants with a 14% error rate or higher were removed from the data analysis. Eventually, there were 17 participants in the control group and 18 participants in the outcome pressure group.

I. Analysis of Questionnaire data

Analyses were conducted on the subjective pressure ratings posttest, and the STAI-state scores during the pretest vs. posttest.

For the posttest subjective pressure ratings, the mean and standard deviations were 2.71 (1.16) for the control group and 5.22 (0.73) for the outcome pressure group. An independent-samples

T-test conducted on the pressure ratings for the two groups yielded a statistically significant difference (t (33) = 7.722, p<.001). This result indicates that the pressure manipulations worked well on the outcome pressure group: participants in the outcome pressure group felt more pressured than participants in the control group.

The data from the STAI-state questionnaires are listed in Table 1. An ANOVA was conducted on the STAI-state scores using pretest vs. posttest as a within-subjects factor and group as a between-subjects factor. Results showed that there was a significant two-way interaction between STAI-state pre-post and group (F (1, 33) = 11.7, p=.002, η^2 = .262), suggesting that the manner in which state anxiety changed across blocks was different depending on the group. Specifically, there was no difference during the pretest between the two groups (32.4 for the control group and 31.3 for the outcome pressure group; t (33) = .396, p=.695). However, the difference during the posttest was significant (32.7 for the control group and 41.6 for the outcome pressure group; t (33) = 2.422, p=.021), suggesting that participants in the outcome pressure group experienced a higher level of anxiety during the posttest than the control group.

A correlation analysis was also conducted between the pressure ratings and the STAI-state difference score (post-pre). Results showed that there was a significant positive correlation between these two measures (r=.370, R^2=13.69%, p=.029), suggesting that the two measures are consistent with each other. In other words, the higher the increase in the STAI-state score during the posttest, the more pressured participants felt.

II. Analysis of RTs

Given that there were many factors in the experiment design, and the main purpose of the analysis of RTs was to check whether there were any differences among the groups in terms of

RTs in different conditions, separate ANOVAs were conducted for the pretest and posttest in this section. An ANOVA using load and compatibility as the within-subjects factors and group as the between-subjects factor was conducted on RTs for the pretest and posttest separately.

Analysis of the pretest RTs revealed several findings. First, and most importantly, there was no significant three-way interaction between group, load, and compatibility (F (1, 33)=.005, p=.946, η^2 =.000), which suggests that in the pretest, the two groups were the same in terms of the flanker interference effect. Second, there was no significant main effect of group (F (1, 33) =.943, p=.339, η^2 =.028), indicating that overall, there was no RT difference for the pretest between groups. Third, there was a significant two-way interaction between load and compatibility (F (1, 33) = 10.094, p=.003, η^2 =.234), suggesting that the flanker interference effect was different under the low-load vs. high-load conditions. Specifically, the flanker interference effect was larger under the low-load condition (74ms) than in the high-load condition (37ms). Fourth, there was also a significant main effect of load (F (1,33)=266.746, p<.001, η^2 =.890) and a main effect of compatibility (F (1,33) = 47.674, p<.001, η^2 =.591), suggesting that RTs were faster in the low-load condition than in the high-load condition and that RTs in the compatible trials were faster than those in the incompatible trials.

Since there were so many factors in the ANOVA model for RTs, the meanings of the various high-way interactions are not intuitively clear. In order to better interpret the interaction effects between factors, an ANOVA on the flanker effect is conducted and reported in the next section. By directly analyzing the flanker effect, some of the interactions from the RTs analysis can be converted to main effects or lower level interactions. Thus, from here on out, there will not be further discussion of the pretest high level interactions – those results and interpretations will instead be decomposed and elaborated on in the flanker effect analysis section.

Analysis of the posttest RTs also resulted in a number of findings. First, there was a significant three-way interaction between group, load, and compatibility (F (1, 33) = 5.039, p=.032, η^2=.132), indicating that compared to the control group, the pressure manipulation affected the flanker effect differently in the posttest. Second, there was no significant main effect of group (F(1, 33)=.918, p=.345, η^2=.027), indicating that overall there was no RT difference among groups in the posttest. Third, there was a significant main effect of load (F (1, 33)=275.7, p<.001, η^2=.893) and compatibility (F (1, 33)=68.76, p<.001, η^2=.676), suggesting that RTs were faster in the low-load conditions than in the high-load conditions (576ms vs. 735ms) and that RTs in compatible trials were faster than those in incompatible trials (632ms vs. 680ms). Again, more detailed posttest analysis will be shown in the flanker effect analysis section below.

III. Analysis of the Flanker Effect

The flanker effect was computed by subtracting RTs in compatible trials from those in incompatible trials. An ANOVA using block (pretest vs. posttest) and load (low vs. high) as within-subjects factors and group (control vs. outcome pressure) as a between-subjects factor was conducted on the flanker effects. Results showed that there was a marginally significant three-way interaction among block, load, and group (F (1, 33) =3.537, p=.069, η^2=.097).

1. Pretest flanker effect

An ANOVA test with load as the within-subjects factor and group as the between-subjects factor was conducted on the pretest flanker effects. Results showed that there was no significant interaction between group and load (F(1,33)<1, p =.946, η^2 =.000). This suggests that, in the pretest, there was no difference between the groups in the flanker effect under different load conditions. There was a significant main effect of load (F(1, 33) = 10.09, p=.003, η^2 =.234), which indicates that the flanker effect under the low load was significantly higher than that under the high load.

2. Posttest Flanker effect

The ANOVA on the posttest flanker effect revealed a significant two-way interaction between group and load (F (1, 33) = 5.039, p=.032, η^2 =.132), suggesting that compared to the control group, the outcome pressure manipulation modulated the flanker effect differently under different perceptual loads. Specifically, post-hoc analysis showed that there was no difference between groups in the low-load condition (59ms vs. 70ms for the control and outcome pressure groups, respectively; t (33)=.928, p=.360). However, there was a significant difference between groups in the high-load condition (6ms vs. 55ms for the control and outcome pressure groups, respectively; t (33)=.2.913, p=.006). In addition, the traditional perceptual load effect (i.e., a larger flanker effect under low load than under high load) disappeared for the outcome pressure group (t (17)=1.03, p=.314), but was present in the control group during the posttest (t (16)=5.74, p<.001).

There was a significant main effect of load (F (1, 33) =15.68, p<.001, η^2 =.322), indicating that overall the flanker effect under low load (65ms) was larger than that under high load (31ms). Finally, we also found a significant main effect of group (F (1, 33) = 6.692, p=.014, η^2 =.169), suggesting that the overall flanker effect in the outcome pressure group (63ms) was larger than that in the control group (33ms).

Discussion

First of all, Experiment 1 replicated the traditional finding of a load effect in the low-pressure condition, that is, that the flanker effect in the low perceptual load is larger than that in the high perceptual load (Lavie, Hirst & de Fockert, 2004; Beck & Lavie, 2005; Forster & Lavie, 2008). Most importantly and interestingly, however, we found that the flanker effect under load was modulated by the outcome pressure manipulation. Specifically, in the high outcome pressure situation, the perceptual load effect disappeared such that the flanker effects under the low load and the high load were of the same magnitude.

Compared to the low-pressure situation, the flanker effect under high pressure was larger in the high-load condition. This result was consistent with Sato et al. (2012). However, the experiment did not replicate the eliminated flanker effect under high pressure and low perceptual load that they found. There could be multiple reasons for this. First, the experiment used a different flanker task, and perceptual load was also manipulated differently. The perceptual load in Sato et al. (2012) was manipulated by changing the set size, whereas in this study, perceptual load was manipulated by varying the homogeneity of distracters to change the perceptual complexity. The set size manipulations may interact with pressure in a different manner than display homogeneity does. With a fixed display size (as was the case here), there is always the same amount of information to take in and analyze, whereas that is not the case when one manipulates set size. At smaller set sizes, there is less processing to do, and thus less need to filter. Second, the target in Sato et al (2012) was always in the center (i.e., in one of the three columns in the center area), while the distractors were in the periphery. In contrast, the distractor in Experiment 1 was in the center and the target was in the periphery. It is possible that the location of the flanker and the target is important under high pressure. For example, centrally located distractors would be harder to avoid, compared to distractors in the periphery. Third, the pressure manipulations were also different. Participants in Sato et al.'s study were put into a highly stressful situation. However, the stress was not directly related to the flanker task itself. In this study, high pressure was directly related to performance in the flanker task itself.

In Experiment 1, the pressure effects on selective attention under load were only observed in the high perceptual load condition. However, it remains unclear whether this is due to an inability to filter the distractor at fixation under pressure, or whether it is a "central" failure to filter task-relevant distractors in general, regardless of the positions. If the former is true, one would expect that moving the distractor away from the center would make selective attention immune to a high-pressure situation. If the latter is true, however, one would expect to see that selective attention is vulnerable to a high pressure situation no matter where the distractor is. Experiment 2 will address this issue.

Finally, according to the load theory of Lavie and her colleagues (1994, 2004), perceptual load works more like a passive filter. Under high perceptual load, distractors are filtered due to a lack of attentional resources to process them. Cognitive load was discussed only under a low perceptual load condition, in which there are still free attentional resources left for cognitive load to play a role. However, the results from Experiment 1 are inconsistent with load theory. It is possible that instead of perceptual load being totally passive, it could still be an active filter. We will return to this discussion in the general discussion section of this dissertation, after more evidence has been collected in subsequent experiments to verify the pressure effects.

3.2 Experiment 2: Does the distractor location matter under pressure?

In Experiment 1, it was found that when the distractor (or flanker) was presented at the fixation location, the flanker effect was increased under the high outcome pressure condition relative to the control condition. However, it remains unclear whether location of the flanker would interact with pressure effects. Beck and Lavie (2005) found that when the distractor was put at the central fixation location, it was more difficult to filter out, compared to when it was on the peripheral location. It is possible that the increased flanker effect under pressure could in part be due to the location of the flanker. When people are in a stressful and anxious situation, temporary tunnel vision could possibly occur and thus lead to a reduced Useful Field of View (Hockey, 1970a; Williams, 1988). Therefore, it is possible that if pressure reduces the UFOV (Useful Field of View), distractors placed outside the search display would be treated in a much different way than when they appear at fixation. In particular, compared to central distractors, peripheral distractors would be more likely to get ignored under pressure. In that case, we would expect to see a reduced flanker effect for peripheral distractors under pressure. Experiment 2 will test this.

Experiment 2 is the same as Experiment 1, except that the distractor is moved from the central fixation location to the peripheral location (either left or right). If pressure reduces the UFOV, then there will be a smaller flanker effect under high pressure as opposed to the larger effects we found in Experiment 1. However, if pressure acts to disrupt attentional control (in terms of a lack of control to filter distractors), then we should once again replicate the results in Experiment 1. In this case, we should see a larger flanker effect in the high-load condition under high pressure than under low pressure.

Method

Participants

Forty naïve participants (23 female; age range, 18-32 years) were recruited from the University of Illinois at Urbana-Champaign through online advertisements. Participants were randomly assigned to the two groups, with 20 in each group. All of the participants had normal color vision and either normal or corrected-to-normal visual acuity. They all got paid $10 for their participation, with participants in the outcome pressure group receiving an extra $10 for $20 total (which was part of the pressure manipulation).

Stimuli, Apparatus, and Procedure

The stimuli, apparatus, and procedure were the same as in Experiment 1 except that the distractor (or flanker) was moved from the center to the periphery. The distractor was positioned 3.5 degrees to the left or the right of the fixation.

Results

Participants with a 14% error rate or higher were removed from data analysis, leaving 19 participants for each group.

I. Analysis of Questionnaire data

First, the analysis of pressure ratings was done as in Experiment 1. The mean and standard deviation of pressure ratings for the control and outcome pressure groups were 3.05 (1.39) and 5.53 (0.96), respectively. The independent-samples t-test showed that there was a significant difference between the control group and the outcome pressure group ($t(36)=-6.36$, $p<.001$), which indicates that the outcome pressure manipulation worked according to the subjective ratings of experienced pressure level.

Analysis on the STAI-state data was also conducted in the same way as in Experiment 1. Results showed a significant two-way interaction between STAI-state pre-post and group (F (1, 36) =11.7, p=.002, η^2=. 246), suggesting that during the pretest and posttest, the manner of change in state anxiety was different for the two groups. Post-hoc analysis showed that the change in anxiety level was larger for the outcome pressure group than for the control group (t (36)=-3.426, p=.002). This is further indication that the outcome pressure manipulation was effective.

Correlation analysis between the pressure ratings and the STAI-state difference score revealed a significant correlation between these two measures (r=.531, R^2 =28.2% p=.001). As in Experiment 1, this result shows that the pressure ratings and STAI-state were consistent with each other.

II. Analysis of RTs

As in Experiment 1, an ANOVA was conducted on RTs using load and compatibility as within-subjects factors and group as a between-subjects factor separately for both the pretest and posttest.

Analysis of the pretest RTs revealed several things. First, there was no three-way interaction for group, load, and compatibility (F (1, 36) =1.558, p=.220, η^2=.041), suggesting that during the pretest session, the two groups were the same in terms of the flanker effect under the two load conditions. Second, there was no significant main effect of group (F(1, 36) = .268, p=.608, η^2=.007), indicating that, overall, there was no RT difference among groups during the pretest session. Third, there was a significant two-way interaction between load and compatibility (F (1,

36) =31.019, p<.001, η^2=.463), which indicates that the flanker effect was different under high load than under low load. Fourth, there was a significant main effect of load (F (1, 36) = 278.611, p<.001, η^2=.886), indicating that RTs were faster in the low-load condition than in the high-load condition. There was also a significant main effect of compatibility (F (1, 36) = 22.911, p<.001, η^2=.389), suggesting that RTs in the compatible trials were faster than in the incompatible trials. All the other possible two-way or three-way interactions were not significant.

Analysis of posttest RTs yielded four findings. First, there was a significant three-way interaction for load, compatibility, and group (F (1, 36) = 4.669, p=.037, η^2=.115), reflecting that the pressure manipulation had different effects on the flanker effect. Second, there was no significant main effect of group (F(1, 36) = 1.844, p=.183, η^2=.049), indicating that RTs in the posttest were not different between the two groups. Third, there was a marginally significant two-way interaction between load and compatibility (F (1, 36) = 3.758, p=.06, η^2=.095), which may provide some indication that the flanker effect was different under different load conditions. Fourth, there was a significant main effect of load (F (1, 36) = 295.496, p<.001, η^2=.891) and also a main effect of compatibility (F (1, 36) = 15.569, p<.001, η^2=.302), suggesting that RTs were faster in low load conditions than in high load conditions (533ms vs. 683ms), and RTs in compatible trials are faster than those in incompatible trials (617ms vs. 600ms).

III. Analysis of the Flanker Effect

As in Experiment 1, ANOVA of the flanker effect is conducted in order to better interpret the interaction effect between factors. Specifically, an AVOVA test using block (pretest vs. posttest) × load (high vs. low) × group (control vs. outcome pressure) was conducted on the flanker effect. Results showed that there was a significant three-way interaction (F (1,36)=4.873, p=.034,

η^2=.119), which indicates that the flanker effect under load was different for each group. As with Experiment 1, pretest and posttest were next looked at separately.

1. Pretest flanker effect

An ANOVA test with load as the within-subjects factor and group as the between-subjects factor was conducted on the pretest flanker effects. Results showed that there was a significant main effect of load ($F(1, 36) = 31.019$, $p<.0001$, η^2=.463), which indicates that the flanker effect under low load was significantly higher than that under high load. There was no significant interaction between group and load ($F(1, 36)$ =1.5584, p=.220, η^2=.041), which means that the two groups were not different from each other during the pretest in terms of the flanker effect.

2. Posttest flanker effect

An ANOVA on the posttest flanker effect revealed a significant two-way interaction between group and load ($F(1, 36) = 4.669$, p=.037, η^2=.115), suggesting that the outcome pressure manipulations modulated the flanker effect differently under different perceptual loads. Specifically, the flanker effect was much larger under high load in the outcome pressure group (26ms) than in the control group (-6ms). However, for the low-load condition, the flanker effects were the same for both groups (23ms vs. 24 ms). In addition, the load effect was absent in the outcome pressure group, but remained in the control group. There was also a marginally significant main effect of load ($F(1, 36)$=3.76, p=.06, η^2=.095) and a significant main effect of group ($F(1,36) = 3.84$, p =.05, η^2=.097), indicating an overall larger flanker effect for the outcome pressure group than for the control group.

The overall flanker effects were also compared across Experiments 1 and 2, in which the location of the flanker was different from each other. Results showed that there was a significant main effect between Experiments 1 and 2 ($F(1,71)=20.322$, $p<.001$). Specifically, the flanker effect was larger when the location of flanker was in the center (Experiment 1, mean=52ms), than when the location of the flanker was on the periphery (Experiment 2, mean=20ms). This pattern of results replicates findings in Beck and Lavie (2005).

Discussion

In Experiment 2, the central flanker from Experiment 1 was moved to the periphery to investigate whether the location of the distractor matters for pressure effects. Results showed that, overall, the flanker effect was reduced when the flanker was at the periphery, which is consistent with previous findings (Beck & Lavie, 2005). Most importantly, in the outcome pressure group, it was found that the flanker effect under high load was increased compared to the control group in the post test. This result is a replication of Experiment 1. Combining results from Experiments 1 and 2 then, reveals a robust picture of how outcome pressure affects our ability to filter distractor information. The location of the distractor modulates the flanker interference as a whole (i.e., the main effect of position between Experiments 1 and 2). Regardless of the distraction location, however, outcome pressure produced the same effect on distractor processing – high outcome pressure eliminated the perceptual load effect. In other words, under high perceptual load, participants consistently failed to filter the distractor regardless of its location. The results also suggest that unlike stressors such as speed stress (for driving) and loud noise (Williams, 1988; Hockey, 1970a), the outcome pressure in these studies did not create tunnel vision. Instead, it disrupted higher level cognitive control. One possible reason for the difference could be that when participants are asked to drive faster, the best strategy they could use is to focus more attention on the central road. Tunnel vision in some sense would help to achieve the required speed for driving. However, in the studies here, when participants were asked to respond faster to a target letter, tunnel vision would have only helped for incompatible trials but not compatible trials.

Before being able to make a conclusion, Experiment 3 will once again test the flanker effect with distractors in the periphery, along with the attentional capture effect, under two pressure manipulations. By partially replicating the design of Experiment 2 for the flanker effects, it may be possible to get a better idea of outcome pressure effects on the flanker effect under load. But in addition, Experiment 3 introduces the factor of task-relevance to see whether pressure affects task-relevant and task-irrelevant distractors differently.

3.3 Experiment 3: Does the relevance of the distractor affect the influence of pressure on performance?

In both Experiments 1 and 2, it was found that high outcome pressure disrupted cognitive control and induced a larger flanker effects under high perceptual load. In both experiments, the distractor or the flanker was always task-relevant because it was a copy of one of the two possible targets. Thus, Experiment 3 is aimed at addressing the issue of whether distractor relevance matters under pressure.

Forster and Lavie (2008) manipulated the task relevance of their distracters, and compared the interference effects from entirely task-irrelevant stimuli (e.g., an image) and task-relevant stimuli (e.g., a flanker) under low versus high perceptual load. The task relevance of the stimuli was determined by whether the stimuli would fit the task set and was associated with any target-response mappings. In their study, they included both flanker trials (80%) and attentional capture trials (20%). The flanker trials were the same as in Experiment 2, and were included to measure interference from task-relevant stimuli. On the other hand, the attentional capture trials were designed to measure the interference from task-irrelevant stimuli by comparing RTs when task-irrelevant distractors are present to RTs when task-irrelevant distractors are absent. If the first RTs are longer, it means that participants spend some time processing those items and that slowed them down compared to when there were no distractors. If, on the other hand, there is no difference in RTs between these two conditions, then this is taken as evidence that participants efficiently filtered this task-irrelevant information.

The task-irrelevant stimuli Forster and Lavie (2008) used were famous cartoon characters such as Sponge-Bob, Spider Man, Mickey Mouse, etc. Those images were assumed to be task-irrelevant because they were unrelated to the letter search task and not associated with any response. Results showed that both task-relevant and task-irrelevant distractors interfered with task performance under low perceptual load; however, the interference went away under high perceptual load.

Experiment 3 will investigate whether pressure modulates interference based on the relevance of the distractor. It will use the same experiment design as Forster and Lavie (2008), with a couple exceptions. First, the ratio of attentional capture trials is increased from 20% to 33.33% in order to obtain enough data per condition for both the pretest and posttest sessions, within the total experiment time (restricted to 60 minutes). Second, instead of using famous cartoon images, non-facial images such as cars, cubes, shoes, etc. are used in Experiment 3 (see Figure 6). The main reason for this change is because it is planned for Experiment 4. In Experiment 4, which we will discuss later, we did use facial stimuli in the search display (emoticons) and non-facial images as capture stimuli to avoid any possible overlap in relevance between the distractors and targets. In addition, by using different sets of images (i.e., using non-facial images rather than cartoon characters), the idea was to replicate Forster and Lavie (2008) on a conceptual level. It is well known that faces command a high level of attentional priority (Theeuwes & Van der Stigchel, 2006; Langton et al, 2008). So it was thought that it might be a good idea to test for the effect of task irrelevancy with images more neutral than faces.

This new design also allows for more clear separation of the two different types of attentional processing with respect to how they are each affected by pressure: the task-irrelevant stimuli (i.e., those in the attentional capture trials) distract attention in a bottom-up way, whereas task-relevant stimuli (i.e., those in the flanker trials) distract attention in a top-down way. By manipulating the distractor relevance to the task, it can be seen how different pressure levels affect selective attention in terms of top-down and bottom-up, separately.

Method

Participants

Forty naïve participants (26 female; age range, 18-32 years) were recruited from the University of Illinois at Urbana-Champaign through online advertisements. All of the participants had normal color vision and either normal or corrected-to-normal visual acuity. They all got paid $10 for their participation, with participants in the outcome pressure group receiving an extra $10 for $20 total (which was part of the pressure manipulation).

Stimuli, Apparatus, and Procedure

The stimuli, apparatus, and procedure were the same as those in Experiment 2 except that attentional capture trials were added to the experiment. In the attentional capture trials, half of them were image present and the other half were image absent. The images were colorful non-facial images as shown in Figure 6, subtending 2.8 to 4 degrees vertically and 2.8 to 3.2 degrees horizontally. They were presented either above or below the letter circle, about 4.7 degrees from the fixation location, and between 0.7 to 1.2 degrees edge to the edge from the nearest circle letter (note that Figure 5 is only a schematic sample of the stimulus display). There were 576 trials total, with 288 trials in each of the two blocks. Within each block, there were 192 flanker trials and 96 attentional capture trials. The two different types of trials were mixed together.

The experiment procedure was the same as in Experiment 2. In Experiment 3, one would expect to replicate the flanker effect results from Experiment 2. That is, one would expect to see a larger flanker effect in the high load under high outcome pressure condition than in the low outcome pressure condition.

For attentional capture effects during the pretest, in general one would expect to see a larger attentional capture effect by images in the low load than in the high load condition. This pattern of results is expected because that is what Forster and Lavie (2008) found. From Experiments 1 and 2 it can be known that pressure affects the ability to filter distractors. However, it is unknown, whether this generalizes to both relevant and irrelevant distractors. If it does generalize to both, then one would expect to find an increase of the attentional capture effect in high load when under high pressure, as compared to a low pressure situation. On the other hand, if participants can learn to filter out the irrelevant distractor no matter what, then one would see no differences between the groups in the posttest.

Results

Participants with a 14% error rate or higher were removed from the data analysis. This screen resulted in 18 participants for each of the two groups.

I. Analysis of Questionnaire data

The mean pressure ratings and standard deviations for the control group and outcome pressure group were 3.67 (1.50) and 5.44 (1.20), respectively. An independent-samples t-test was conducted on the pressure ratings and showed that there was a significant difference between the two groups ($t(34)=-3.94$, $p<.001$). This suggests that according to subjective ratings, the outcome pressure manipulation was quite robust.

For the STAI-state data, the same analysis was performed as in the previous experiments. A two-way ANOVA using the STAI-state (pretest vs. posttest) and group as two factors revealed a marginally significant interaction between group and block ($F(1, 34)=2.966$, $p=.094$, $\eta^2=.08$). This result suggests that participants in the outcome pressure group tended to have a bigger increase in anxiety than the control group.

As in previous experiments, a correlation analysis was done between the pressure ratings and the STAI-state difference scores. However, no significant correlation was found between these two measures ($r=.175$, $p=.308$), which could simply reflect a lack of power because of the small sample size.

II. Analysis of RTs

As in previous experiments, an ANOVA was conducted on RTs using block, load, and compatibility as within-subjects factors and group as a between-subjects factor. This was done for flanker trials and attentional trials separately, to check if there were any four-way interactions. For the flanker trials, results showed that the four-way interaction for group, block, load, and compatibility was not significant (F(1, 34)=2.11, p=.156, η^2=.058). For the attentional capture trials, results also showed an absence of four-way interaction for group, block, load, and compatibility (F(1, 34)=.039, p=.849, η^2=.001). Next, the data during the pretest and posttest separately for the flanker and attentional capture trials was looked at separately.

For the flanker trials during the pretest, analysis of RTs resulted in three findings. First, there was no three-way interaction for group, load, and compatibility (F(1, 34)=.037, p=.849, η^2=.001), indicating that during the pretest, the two groups were not different from each other. Second, there was no main effect of group (F(1, 34)=.410, p=.526, η^2=.012), suggesting that the overall RTs were not different among groups. Third, the two-way interaction between load and compatibility was significant (F(1, 34)=4.748, p=.036, η^2=.123). There was also a significant main effect of load (F (1, 34)=252.651, p<.001, η^2=.881) and a significant main effect of compatibility (F(1, 34)=26.954, p<.001, η^2=.442). These results suggest that RTs in the low load condition were faster than those in the high load condition, and RTs in compatible trials were faster than those in incompatible trials.

For the attentional capture trials during the pretest, RTs analysis showed that there was no three-way interaction for group, load, and image presence (F (1, 34)=1.368, p=.25, η^2 =.039), indicating that there was no difference among groups in terms of the attentional capture effect during the pretest. There was also a significant two-way interaction between load and image presence (F (1, 34)=11.209, p=.002, η^2=.248), which suggests that attentional capture effects were different under low load than high load. Specifically, attentional capture effects were higher under high load (76ms) than under low load (21ms). There were significant main effects of load

(F(1, 34) =176.867, p<.001, η^2=.839) and image presence (F(1, 34)=42.296, p<.001, η^2=.554), suggesting that RTs were faster under low load than high load (547ms vs. 738ms) and were faster when the image was absent than when it was present (618ms vs. 667ms). In sum, the results indicate a greater amount of attentional capture effects by irrelevant stimuli in the high relative to the low perceptual load condition.

During the posttest, analysis of RTs for flanker trials showed that there was a significant three-way interaction for group, load, and compatibility (F(1, 34)=6.969, p=.012, η^2=.17), indicating that the two groups were different in terms of the flanker effect during the posttest. There was also no main effect of group (F(1, 34)=1.567, p=.219, η^2=.044), suggesting that the overall RTs were not different between the two groups. The two-way interaction between load and compatibility (F (1, 34) =13.121, p=.001, η^2 =.278) and between group and compatibility (F(1,34)=6.325. p=.017, η^2 =.157) were also significant. The main effects of load (F(1, 34)=203.599, p<.001, η^2=.857) and compatibility (F(1, 34)=21.453, p<.001, η^2=.387) were significant as well.

Finally, analysis of RTs for posttest attentional capture trials showed that there was only a significant main effect of load (F(1, 34)=254.279, p<.001, η^2=.882) and a significant main effect of image presence (F(1, 34)=20.665, p<.001, η^2=.378), indicating that overall RTs were faster under low load (520ms) than high load (694ms) and faster when there was an image absent (594ms) than when one was present (621ms). However, none of the other possible main effects and interaction effects were significant, suggesting that during the posttest, there were no differences among groups in terms of attentional capture effects. In sum, analysis of the attentional capture data shows that outcome pressure did not have any impact on attentional capture.

III. Analysis of the Flanker Effect

Analysis was also conducted directly on the flanker effect and attentional capture effect, comparing the outcome pressure group to the control group. An ANOVA test using block (pretest vs. posttest) and load (low vs. high) as within-subjects factors and group (control vs. outcome pressure) as a between-subjects factor was conducted on the flanker effects. Results showed that the three-way interaction among block, load, and group was not significant (F (1, 34) =2.11, p=.156, η^2=.058). However, this result could reflect type II error. Next, data during the pretest and posttest are examined separately.

1. Pretest flanker effect

The ANOVA test with load as a within-subjects factor and group as a between-subjects factor was conducted on the pretest flanker effects. Results showed that there was a significant main effect of load (F(1, 34) = 4.748, p=.036, η^2=.123), which indicated that the flanker effect under low load was significantly higher than when under high load. There was no significant interaction between group and load (F (2, 34) =.037, p=.849, η^2=.001), which means that the two groups were not different from each other on flanker effects during the pretest.

2. Posttest flanker effect

The ANOVA of the posttest flanker effect revealed a significant two-way interaction between group and load (F (1, 34) = 6.969, p=.012, η^2=.170), suggesting that the differences between the flanker effects under the high load versus the low load condition were not equivalent for the two groups. Specifically, the flanker effect was much larger under high load (34ms) in the outcome pressure group than in the control group (14ms) (t (34)=-2.909, p=.006), which replicates the results of Experiments 1 and 2. Under the low load, however, the flanker effect was the same between the two groups (t (34) = -1.274, p=.211). There was a significant main effect of load (F(1, 34)=13.12, p=.001, η^2 =.278), indicating that the flanker effect was larger under low load than under high load (34ms vs. 14ms). And there was a significant main effect of group (F(1, 34)=6.325, p=.017, η^2 =.157), which suggests that the flanker effect was larger in the outcome pressure group than in the control group (37ms vs. 11ms). However, given that there was a significant interaction, the main effects here are mostly attributable to the interaction effects described above.

IV. Analysis of the attentional capture effect

The ANOVA test on the attentional capture effect (RTs of image present – RTs of image absent) was conducted by including block and load as within-subjects factors and group as a between-subjects factor. Results showed that there was no significant three-way interaction among block, load, and group (F(1, 34)=.039, p=.845, η^2 =.001), suggesting that the pressure manipulations did not seem to affect the attentional capture effect. However, the two-way interaction between block and load was significant (F(1, 34)=6.941, p=.013, η^2 =.17), indicating that the attentional capture effect under load changed over time. Next data analysis is conducted on the attentional capture effects separately for the pretest and the posttest.

1. Pretest attentional capture effect

The ANOVA test on the attentional capture effect during the pretest was conducted by including load as a within-subjects factor and group as a between-subjects factor. Results showed that there was no interaction between load and group (F (1, 34) =1.368, p=.250, η^2 = .039), which means that the difference in attentional capture effects between high and low perceptual load was the same for the two groups. However, the main effect of load was significant (F (1, 34) =11.209, p=.002, η^2=.248). Surprising and interestingly, attentional capture effects under low load were significantly smaller than those under high load, which was the opposite result from Forster and Lavie (2008). This opposite pattern of attentional capture results will be discussed later.

2. Posttest attentional capture effect

The same analysis was conducted for the posttest. No significant interactions were found between load and group (F(1, 34) = 2.309, p=.138, η^2=.064) and no significant main effect of load was found (F(1, 34) = .192, p=.664, η^2=.006). The main effect of group was also not significant (F(1, 34) = 2.454, p=.126, η^2=.067). These results indicate that the difference of the attentional capture effects between the high and low load went away posttest, and this was true for both groups. However, the overall attentional capture effect was still significant, even though it was small in magnitude (23ms, t (35)=4.59, p<.001 for the low load condition; and 53ms, t (35)=6.086, p<.001 for the high load condition). In sum, significant attentional capture effects were found in the second part of the experiment, but they were not affected by either pressure or load.

Discussion

Experiment 3 once again successfully induced a high pressure situation for participants in the outcome pressure group. The flanker effect results from Experiment 2 were also replicated for the outcome pressure group. That is, It was found that the flanker effect under high load was increased in the high outcome pressure condition. In terms of attentional capture effects, no differences were found between groups, even though it did seem to be the case that a high pressure situation was created for the outcome pressure group. The contrast between the task-relevant stimuli (flankers) and task-irrelevant stimuli (images) suggests that the high pressure situations only disrupt selective attention when the distractors are task-relevant. When the distractors are totally task-irrelevant, attention capture under different perceptual loads would change over time, but is unaffected by pressure. A major difference between the task-relevant and the task-irrelevant distractor is that the task-relevant distractor interferes with selective attention in a top-down way, whereas the task-irrelevant distractor interferes in a bottom-up way. In this sense, it could be argued that outcome pressure does not impact bottom-up interference. Thus, outcome pressure affects the processing of task-relevant stimuli but not task-irrelevant stimuli.

Finally, Experiment 3 found the opposite pattern of attentional capture effects than was found in Forster & Lavie (2008). In the study here, larger attentional capture effects under high load were found (in the pretest) than under the low load. Obviously, this pattern of results is inconsistent with load theory. According to load theory, if a high perceptual load leads to less available attentional resources, then one would expect to see less of an attentional capture effect under high load than under low load. What could possibly lead to this opposite pattern of results? One possibility is the different images that were used. Experiment 3B will address this issue.

Experiment 3B: Do images matter in the attentional capture effect under different perceptual loads?

Experiment 3 found two separate occasions (once in each pre-test experimental group) an opposite pattern of attentional capture effect than in Forster and Lavie (2008). One major difference between this study and their study was the images used. In the study here, non-facial images were used, whereas in their study, facial images (i.e. famous cartoon characters) were used. Thus, Experiment 3B tried to replicate Experiment 3 by using the famous cartoon characters as well. Since in this experiment the only concerned was whether the different attentional capture results were driven by the different images, only a control group was run without any pressure manipulations. If the different images affect attentional capture under perceptual load differently, then load theory would have to be revised for the interference from task-irrelevant stimuli.

Method

Participants

Seventeen participants (8 female; age range 18-22 years) were recruited from the subject pool at University of Illinois at Urbana-Champaign. All of the participants had normal color vision and either normal or corrected-to-normal visual acuity. They received one course credit for their participation.

Stimuli, Apparatus, and Procedure

The stimuli, apparatus and procedure were the same as in Experiment 3 except that instead of using non-facial images, six famous cartoon characters were used: Donald Duck, Mickey Mouse, Pikachu, Spiderman, Sponge Bob, and Superman (see Figure 9).

Results

Participants with a 14% error rate or higher were removed from the data analysis. Eventually, data from one participant was removed, and 16 participants were included in the final data analysis. Mean reaction times, the flanker effect, and the attentional capture effect are listed in Table 9 and Table 10, in order to make them comparable to the previous experiments.

An ANOVA was conducted on the flanker effect and the attentional capture effect. Results showed that there was a significant main effect of load for flanker trials. Specifically, the flanker effect was higher under low load, compared to that under high load (F (1, 15) = 5.114, p=.039, η^2 =.254). And there was also a significant main effect of load for attentional capture effects (F (1, 15) = 4.647, p=.048, η^2 =.237): the attentional capture was smaller under low load, compared to under high load, which replicates the results of Experiment 3.

Discussion

Experiment 3B failed to replicate the attentional capture effects under different perceptual load in Forster and Lavie (2008), even using the same famous cartoon characters that they used. However, the attentional capture effects under load from Experiment 3 were replicated. That is, once again, larger attentional capture effects were found under high load compared to when under low load. Looking further at the details of the experiment design, one of the differences between our study and Forster and Lavie (2008) is the ratio of attentional capture trials. In their study there were 20% attentional capture trials, and in our study, there were 33.3%. The other difference in experiment design is the duration of the search display, with 100ms in their study and 200ms in our study. However, it seems relatively unlikely that the timing difference would all of a sudden change the pattern of attentional capture effects under load. However, the ratio difference might be an important factor.

In sum, two separate experiments consistently found a pattern of attentional capture effects under load – that is opposite of results from previous studies. In order to explain the robust pattern of attentional capture effects under load in these studies here, it can be argued that when the search display of letters was presented along with a colorful image, the difficulty of the search task was increased much more under high load than under low load. One possibility is that under high load, all the letters in the search display are equally difficult to attend, and therefore the whole display groups into a difficult-to-attend group of letters. When this group appears along with a very different type of image, the salience and ease of selection of the cartoon image are relatively increased. In contrast, under low load, the distractors are similar and create a pop-out effect of the target letter. Thus, the target is easier to select and it is therefore harder for the cartoon image to compete for attention.

However, at this point, it is still unclear as to why the exact opposite pattern of results from Forster and Lavie (2008) were found, given that Experiment 3 used a similar design and images. As discussed above, exploring the importance of the ratio difference of attentional capture trials could be a good basis for follow-up study in order to elucidate this inconsistency across labs.

3.4 Experiment 4: Selective attention to emotional stimuli under pressure

The first three experiments examined the non-emotional stimuli of letters. In contrast, Experiment 4 investigates how pressure affects selective attention to the emotional stimuli of emoticons. Studies have shown that negative, angry, and threatening faces will often automatically capture attention (e.g., Eastwood, Smilek, & Merikle, 2001; Fenske & Eastwood, 2003; Fox, Russo & Dutton, 2002). Hortsmann, Borgstedt, and Heumann (2006) combined a flanker paradigm with emotional faces and found a flanker-effect asymmetry for emotional stimuli. Specifically, the flanker effect was found to be stronger when positive faces were target flankered by negative faces than when negative faces were target flankered by positive faces. One possible reason for this flanker effect asymmetry is that negative faces tend to automatically attract attention, so when the target is a negative face, the distractor may not have as much effect.

On the other hand, when the target is a positive face with negative distractors (or flankers), attention will be captured by the distracters, which will in turn slow down responses to the target.

Experiment 4 included both flanker trials and attentional capture trials as Forster and Lavie (2008) did. One third of the trials were attentional capture trials and the rest were flanker trials. There were a total of 576 trials. Participants were required to search for a non-neutral face (either a sad or happy face) among neutral faces arranged in an imaginary circle and then press the left arrow key for a happy face or the right arrow key for a sad face (the target response mapping is counterbalanced across participants). In flanker trials (see Figure 12), the distractor (always in the center) was either a sad or happy face. There were four conditions: happy target presented with sad distractor (i.e., the happy target incompatible condition), happy target presented with happy distractor (i.e., the happy target compatible condition), sad target presented with happy distractor (i.e., the sad target incompatible condition), and sad target presented with sad distractor (i.e., the sad target compatible condition). Each trial started with a fixation dot at the center of the screen for 2s, followed by the search display. In attentional capture trials (see Figure 10), half of the time there was an abrupt image onset 50ms after the search display appeared. The other half of trials were image absent trials, which were included to provide a baseline measure for attentional capture effects. Attentional capture trials and flanker trials were all mixed together.

Note that the experiment design of the attentional capture trials was revised from Forster and Lavie (2008) in three ways. First, given that the search task was related to faces, using non-face images as attentional capture distracters would be more appropriate so as to avoid any task-relevance issues. Second, each display was presented until response or up to 3 seconds, whichever came first. This was done because the search task takes a long time and it would be an extremely difficult task if the search display was presented only briefly. Third, the images were presented 50ms after the search display with emoticons. This delay was included to increase the bottom-up salience of the capture images (Yantis & Jonides, 1990).

The two groups in this experiment were the same as in Experiment 1, and all the pressure manipulations were the same. We have two predictions for this experiment. First, the traditional findings of a flanker effect asymmetry for emoticons would be replicated. Specifically, one would expect to see a bigger flanker effect when a happy face is the target than when a sad face is the target. Using the same logic, if a sad target captures attention more easily, we would also see a bigger attentional capture effect by image onsets when the happy face is the target than when the sad face is the target. Second, as for the pressure effect, there are two possibilities to consider. If pressure weakens executive control, then sad faces would capture attention more strongly, and this would speed up the response to sad face targets. Also, in this case, both the flanker effect asymmetry and the attentional capture asymmetry will be further increased under pressure. However, the other possibility is that pressure could reduce processing of the emotional valence and therefore reducing the differences in effect between the happy and sad faces.

Method

Participants

Forty-two participants (25 female; age range, 18-32 years) were recruited from the University of Illinois at Urbana-Champaign through online advertisements. All of the participants had normal color vision and either normal or corrected-to-normal visual acuity. They were all paid $10 for their participation, with participants in the outcome pressure group receiving an extra $10 for

$20 total (this was part of the pressure manipulation). The number of participants in each of the two groups was 21.

Stimuli, Apparatus, and Procedure

The stimuli, apparatus, and procedure were the same as those in Experiment 3 except that instead of using letters, the search display consisted of emoticons of either happy, neutral, or sad faces (see Figures 10 and 11). The visual angels for the target emoticons and non-target emoticons were 0.62 degrees vertically and horizontally. The distractor emotion was 1.3 times larger than the other emoticons.

Results

Participants with a 14% error rate or higher were removed from the data analysis. Eventually no participants were removed, and there were 21 subjects each for both the control group and outcome pressure group.

I. Analysis of Questionnaire data

The mean pressure ratings and standard deviations are: 3.81 (1.54) for the control group and 5.448 (1.37) for the outcome pressure group. The independent-samples t-test showed that there was a significant difference between the control group and the outcome pressure group (t(40)=-3.72, p<.001). Once again, the results based on subjective ratings indicate that the outcome pressure manipulation was robust.

The ANOVA test on STAI-state by including block (pretest vs. posttest) as a within-subjects factor and group as a between-subjects factor showed a marginally significant interaction between block and group (F (1, 40)=3.258, p=.079, η^2 =.075). Specifically, it could be that the

STAI-state for the outcome pressure group was larger in the posttest compared to in the pretest (36.1 vs. 30.1). However, for the control group, the STAI-state scores remained the same during the pretest and posttest (34.9 vs. 35.4). There was also a significant main effect of block (F (1, 40)=4.746, p=.035, η^2=.106), which means that the anxiety level in the posttest increased in general. Together, these results showed that there was a tendency for the anxiety level to increase in the outcome pressure group, but not in the control group.

The correlation between the pressure ratings and the STAI-state difference score was not significant (r=.247, p=.114). However, when looking only at the STAI-state posttest score, these were significantly correlated with pressure ratings (r=.512, p=.001), which suggests that the pressure ratings and post STAI-state scores were consistent with each other.

II. Analysis of RTs, flanker effects, and attentional capture effects

The same analyses were conducted as in Experiment 3. The ANOVA was conducted by including group as a between-subjects factor, and block (pretest vs. posttest), target emotional valence (happy target vs. sad target), and compatibility for flanker trials (incompatible vs. compatible) or image presence for attentional capture trials (image present vs. image absent) as within-subjects factors. Results showed that for flanker trials, there was no significant four-way interaction among block, target emotional valence, compatibility, and group (F(1, 40)=1.397, p=.244, η^2=.034), suggesting that pressure manipulations did not seem to affect the flanker effect under different target emotional valence conditions.

For the attentional capture trials, results showed that there was also no significant four-way interaction among block, target emotional valence, image presence, and group (F(1, 40)<1, p=.987, η^2 =.000), indicating that pressure manipulations also did not affect the attentional capture when the target was in different emotional valence conditions. However, there was a significant three-way interaction among block, image presence, and target emotional valence (F(1, 40)=12.102, p=.001, η^2 =.232), suggesting that the attentional capture effects under different target emotional valence changed over time. The results for the attentional capture effects were consistent with those found in Experiment 3.

The pretest and posttest tests were also analyzed separately in order to examine further how different factors affect the flanker effects and the attentional capture effects in each block.

Analysis of RTs for flanker trials during the pretest resulted in three findings. First, there was no three-way interaction for group, target emotional valence, and compatibility (F(1, 40)=1.857, p=.181, η^2 =.044). This indicates that, during the pretest, the two groups were not different from each other in terms of a flanker effect difference between a sad target and a happy target. Second, there was no main effect of group (F(1, 40)=1.06, p=.309, η^2 =.026), suggesting that the overall RTs were not different between groups. Third, the two way interaction between target emotional valence and compatibility was significant (F(1, 40)=35.246, p=.000, η^2 =.468). Specifically, when the target was a sad face, the compatibility effect was much smaller compared to when the target was a happy face (-22 ms for sad targets versus 68ms for happy targets). There was also a significant main effect of target emotional valence (F(1, 40)=44.406, p<.001, η^2 =.526) and a significant main effect of compatibility (F (1, 40)=13.806, p=.001, η^2 =.257), suggesting that the RTs for sad targets were faster than those for happy targets (852ms vs. 953ms), and the RTs for compatible trials were faster compared to incompatible trials (891ms vs. 914ms).

During the posttest, analysis of RTs for flanker trials showed exactly the same pattern of results as in the pretest. There was no three-way interaction for group, target emotional valence, and compatibility ($F(1, 40)=.007$, $p=.933$, $\eta^2=.000$), indicating that the flanker effect difference between sad targets and happy targets for the two groups was equivalent. Second, there was no main effect of group ($F(1, 40)=2.007$, $p=.164$, $\eta^2=.048$). There was, however, a significant interaction effect between target emotional valence and compatibility ($F(1, 40)=25.238$, $p<.001$, $\eta^2=.387$). The main effects of target emotional valence ($F(1, 40)=85.966$, $p<.001$, $\eta^2=.682$) and compatibility ($F(1, 40)=39.235$, $p<.001$, $\eta^2=.495$) were also significant. These results show that the pressure manipulations did not seem to affect the flanker interference effect for emotional stimuli in this study.

Analysis of RTs for attentional capture trials during the pretest showed that there was no three-way interaction for group, target emotional valence, and image presence ($F(1,40)=.151$, $p=.700$, $\eta^2=.010$). This suggests that the two groups were the same in terms of the difference of attentional capture effect in the two emotional target conditions. Also, there was a significant two-way interaction between target emotional valence and image presence ($F(1, 40)=13.415$, $p=.001$, $\eta^2=.251$). Specifically, when the target was a sad face, attentional capture effects were much smaller than when the target was a happy face (31ms for sad targets versus 91ms for happy targets). The main effects of target emotional valence and image presence were also significant ($F(1, 40)=52.728$, $p<.001$, $\eta^2=.569$ for target emotional valence; $F(1, 40)=23.906$, $p<.001$, $\eta^2=.374$ for image presence), suggesting that the RTs for sad targets were faster than those for happy targets (803ms vs. 915ms), and RTs in the image present condition were slower than those in the image absent condition (889ms vs. 829ms).

Finally, analysis of RTs for the posttest attentional capture trials showed no significant three-way interaction for group, target emotional valence, and image presence (F(1,40)=.259, p=.614, η^2 =.006), suggesting that different pressure manipulations did not interact with the attentional capture effect when searching for an emotional target. Unlike in the pretest, the interaction effect between target emotional valence and image presence was not significant (F(1, 40)=.099, p=.755, η^2 =.002), as the attentional capture effect was the same for both target types in the posttest. In addition, the absence of a main effect of image-presence in different target types indicate that the attentional capture effect was eliminated in the posttest (F (1, 40)=.891, p=.351, η^2 =.022).

Discussion

In Experiment 4, first a larger flanker effect was found when the target was a happy face than when the target was a sad face. This flanker effect asymmetry is consistent with previous findings using emotional stimuli (Hortsmann et al, 2006). Second, unlike with the non-emotional stimuli of letters, Experiment 4 failed to find any pressure effects for the emotional stimuli of emoticons, for both task-relevant distractors (i.e., non-neutral emoticons) and task-irrelevant distractors (i.e., images). In other words, this study found for the first time, a type of stimuli that appears immune to the effects of outcome pressure that were present in the first three experiments. There are several possible reasons for the absence of outcome pressure effects in this case. First, it could be that by chance, this study just failed to observe the effect. Second, it possibly reflects the uniqueness of the search stimuli used. Emotional faces are special in selective attention in many ways (Bradley et al., 1997; Mather & Cartstensen, 2003). Given that emotional faces are so special, it could be argued that the attentional guidance of emotional faces is immune to pressure. However, more follow-up studies need to be conducted to clarify this issue. Third, it is also possible that the task itself is a low perceptual load condition, regardless of whether the target is a happy or sad emoticon. However, given that the RTs in this experiment are much longer than the high load conditions in the first three experiments, the low load account seems unlikely. In order to deal with the long RTs issue in this experiment, a follow-up study could use a detection task instead of the current discrimination task to reduce the RTs. And it could be tested whether different pressure levels would affect emotional stimuli using detection tasks.

CHAPTER 4 GENERAL DISCUSSION

The current work investigated selective attention under different pressure manipulations and different perceptual load conditions. Specifically, selective attention was measured by a flanker task, the pressure manipulation examined was outcome pressure, and perceptual load (high vs. low) was manipulated by varying search display complexities. The first three experiments investigated selective attention for the neutral stimuli of letters. Throughout Experiments 1 to 3, clear evidence was found of the outcome pressure effect on top-down selective attention as measured by the flanker task. That is, outcome pressure produced a larger amount of flanker interference effect under high perceptual load, regardless of whether the distractor or the flanker was at the center or the periphery. However, bottom-up attention capture driven by irrelevant, but salient images was unaffected by outcome pressure. Experiment 4 examined selective attention for the emotional stimuli of emoticons and found that the outcome pressure effect on the flanker task disappeared, despite its robustness and consistent presence in the first three experiments.

4.1 Pressure, anxiety, and the flanker effect

The term “pressure” has been used in the choking-under-pressure literature for decades (Hardy et al, 1996; Beilock et al 2004; Beilock & DeCaro, 2007). Surprisingly though, no one has investigated what kind of emotion(s) are elicited in lab-created pressure situations. It could be that anger, fear, anxiety, and worry are all classified under the umbrella of “pressure”. In addition, the elicited emotions could be different for different participants and different emotions displayed in pressure situations could also affect the direction of “pressure effects”. Across all four experiments in this dissertation, pressure ratings are highly correlated with STAI-state.

Compared to Sato et al. (2012) in which acute stress manipulations were successfully adopted to create a high stress situation, the experiments here also reliably induced a high pressure situation. A natural question to ask would be whether the outcome pressure effect is mediated by state anxiety. In Sato et al. (2012), the acute stress manipulation produced an average increase of 10 on STAI-state scores during the posttest, whereas in the studies described here, outcome pressure upped STAI-state scores by an average increase of 9 – an increase that is quite comparable to the one fostered by acute stress in Sato et al. (2012). Given that in both Sato et al.'s study and the studies in this dissertation, there were similar STAI-state changes observed before and after pressure/stress manipulations, one might expect to see similar patterns of pressure and stress effects on flanker tasks. However, unlike Sato et al. (2012), the experiments here did not replicate the absence of a flanker effect in the low load under the high anxiety condition. Instead, it was found that the flanker effect in the low load condition was unaffected by pressure manipulations. There are two possible reasons for the different results in the low load condition between the two studies. The first reason could be the different displays used in the two studies (as shown in Figure 14). In the studies described here, perceptual load was manipulated by varying display complexity, and the target was presented in the peripheral search array, whereas in Sato et al. (2012), perceptual load was manipulated via set size changes, and the target was on the central array (i.e., one of the three columns). Under the low perceptual load condition, high pressure (or acute stress) could potentially enhance attentional selection when the target is in the center area and when the set size is small, (which was the case in Sato et al.), but disrupt attentional selection when the target is in the periphery with a relatively large set size (i.e., as in these studies). The second reason could be that the anxiety change cannot wholly explain the pressure effect. There may be some other component differences between outcome pressure and acute stress that lead to the different pattern of results. Further studies could be done to shed more light on this issue.

Notice that in both Sato et al.'s (2012) study and the studies here, the post STAI-state was measured after participants finished the main attention task. One might argue that this measure probably underestimates anxiety level because participants might feel more relaxed after they have finished the task. Also, the anxiety level could possibly reduce over time. In order to resolve these issues in future studies, a more sensitive measure would be to move administration of the STAI-state to right after the pressure manipulations, or in the middle of the second block.

Given that both outcome pressure in these studies and acute stress in Sato et al. (2012) are highly correlated with anxiety level, and under high-anxiety levels individuals' selective attention is impaired, an interesting extension of this research is to study how people with obsessive-compulsive disorder (OCD) would be affected in their selective attention. OCD refers to an anxiety disorder characterized by intrusive and impulsive thoughts (e.g., contamination concerns) that create anxiety, fear, or worry, and foster "repetitive or ritualistic actions" (e.g., excessive washing or cleaning) aimed at decreasing the associated anxiety and corresponding negative feelings (Stein, 2002). It is considered one of the most prevalent and disabling psychiatric disorders (Weissman et al., 1994). OCD is most likely caused by a myriad of psychological and biological factors, and has been found to be associated with various neurological impairments (Lawrence, 2000). People with OCD were also known to have deficits in selective attention, such as difficulty in ignoring irrelevant stimuli and selectively attending to relevant stimuli (Cohen, Lachemeyer, & Springer, 2003). Based on what was found in the studies here, it could be that the selective attention ability of OCD sufferers is comparable to the effects experienced by participants in the outcome pressure group. In other words, one would expect to see the same or similar disrupted cognitive control in the OCD group. Future studies could test this hypothesis by using the same experiment design in our study and compare normal people and people with OCD. The research findings here suggest that compared to normal people, people with OCD would show an increased flanker effect in the high perceptual load condition.

4.2 Choking under pressure and cognitive control

Previous studies have shown that distraction theory explains the effects of outcome pressure (DeCaro et al., 2011; Markman et al., 2006). However, no one has ever tested attention by itself. Rather, prior work has used, for example, math problem solving tasks (Beilock et al, 2005) or categorization tasks (Markman et al , 2006). A preliminary study by the dissertation author and colleague (Chu et al., 2010) tested the pressure effects on endogenous attentional control using the Posner-cuing paradigm (Posner, 1980; Posner & Cohen, 1984) and colored dots as endogenous cues to indicate the possible target locations. It was found that high pressure disrupted endogenous control - specifically, under high pressure, the cuing effect disappeared. In other words, endogenous attentional control “chokes” under pressure.

The current studies manipulated pressure and directly tested selective attention using a flanker task, and conceptually replicated the results of “choking under pressure” studies that used either math problem solving tasks (Beilock, 2007) or categorization tasks (Markman et al, 2005). In the studies here, people did not significantly improve under performance pressure; instead they were less effective at filtering especially when the search task was more difficult (i.e., under the high-load condition). This was comparable to what Beilock and colleagues found using math problem solving tasks (Beilock & Carr, 2001; Beilock & Carr, 2005; Beilock, 2008). In their study, they found evidence of “choking under pressure” for difficult math problems, but not for easy math problems. Similarly, here, choking under pressure only occurred in the high perceptual load condition and not the low-load condition. Together, these findings suggest that high pressure affects executive (or cognitive) control, and this effect is particularly visible when the need for control is high (i.e., either because the math problem is more complex, or because the perceptual information is more complex).

Previous studies have shown that the introduction of some stressors (i.e., loud noise or speed stress) can temporarily create tunnel vision (Williams, 1988; Hockey, 1970a; 1970b). Since outcome pressure here was induced by incentives to respond more quickly and accurately to targets, it might be a potential stressor candidate to create tunnel vision, especially given that it contains a “speed stress” component. If outcome pressure also creates tunnel vision, one might expect to see that the location of a distractor (or a flanker) would play an important role. Specifically, outcome pressure would have disrupted selective attention in Experiment 1 when the distractor was in the center, and would not have affected attention when the distractor was moved to the periphery in Experiment 2. However, contrary to this hypothesized pattern, it was found that in both Experiment 1 and 2, selective attention was impaired regardless of distractor locations. Therefore, these results suggest that the outcome pressure in the studies did not create tunnel vision. Instead, it seems that outcome pressure impaired cognitive control.

How can we reconcile these apparently contradictory results? The key is likely to be the different attentional requirements between driving tasks and the tasks tested here. When driving under speed stress, the central area of the world (the focus of expansion) contains the most important information to succeed in guiding the car; therefore, tunnel vision in this case is a good adaptive strategy to achieve high performance at the required driving speed. In the studies here, however, the absence of tunnel vision could be due to the particular arrangement of stimuli in the flanker tasks and the attentional requirement of the task. For example, the target was in the periphery, and so participants had to retain a somewhat wide attentional focus to complete the task. In addition, the flanking distractor was an onset that matched the attentional set for the task. Therefore, wherever it occurred in the display, it probably captured attention (Folk et al, 1992; Gibson & Kelsey, 1998). Tunnel vision, or purely narrowing attention to the restricted central area, would be counterproductive, as it would focus attention away from the target. It is possible that if the target had been presented centrally and all the relevant information was at fixation, pressure could possibly produce the same tunnel vision effect as in the driving situation. Further studies should be conducted to test this possibility. At any rate, the tasks used here really forced participants to attend widely.

4.3 Perceptual load: A purely passive filter?

As proposed by Lavie and colleagues (Lavie, 1995; Lavie & Cox, 1997; Lavie et al, 2004), under low perceptual load, the search task does not consume much of limited attentional resources, and thus more left-over attentional resources would automatically be used to process the distractor (or flanker). Under high perceptual load, however, there will be less left-over resources for distractor processing. The reduced flanker effect observed under high load then, is merely due to the lack of availability of attentional resources for distractors. In other words, high perceptual load produces passive rejection of the distractor. However, the idea of a purely passive filter created by high perceptual load is challenged by the results of the studies here. If perceptual load is purely passive, one would predict that the flanker effect under high perceptual load would be unaffected by pressure. The results here show otherwise. The increased flanker effect under high load and high outcome pressure suggest that the higher level cognitive control to maintain the stimuli priorities was disrupted by pressure.

Under high perceptual load, rather than passively filtering out distractors, this dissertation argues that our attentional control system could alternatively produce an active enhancement of the target, along with the suppression of the distractor. Under the high-pressure situation, distractor suppression was reduced and thus produced an increased flanker interference effect under high load. The data across all three experiments are in accord with this active filter account. In other words, pressure affects the central process that is responsible for setting attentional priorities, like active suppression. And under high pressure, this central process falters, especially in situations of high perceptual load.

In terms of the interference effect driven by top-down versus bottom-up, the absent pressure effects on task-irrelevant stimuli seem to suggest that bottom-up reflexive attention is unaffected by pressure. This offers further evidence that pressure disrupts central processing.

The active filter account for perceptual load is also consistent with what Torralbo and Beck (2008) argued. In their study, they proposed a neural mechanism underlying perceptual load: the stimuli in the search display create competitive interactions in the visual cortex, and thus some biasing mechanisms are required to resolve the competition so that target processing can be prioritized. In the high perceptual load condition, a stronger biasing mechanism is needed for target processing. And high pressure would disrupt this biasing mechanism, therefore leading to a larger interference effect from the distractor. However, stimuli at fixation will naturally tend to dominate competitive interactions, and stimuli in the periphery will naturally be disadvantaged. So when the target is peripheral, top-down control is needed to bias competition in favor of the target and against the distractors. And pressure in this case would disrupt that top-down control. When the target is central and the distractors are peripheral, top-down control is not needed (at least not as strongly), so pressure would not be as disruptive. Further studies need to be conducted to test this possibility by using displays with a central target and peripheral flanker.

4.4 Attentional capture effects under load

The two experiments in this dissertation found the unexpected opposite pattern of the attentional capture effects under load than was found in Forster and Lavie (2008). According to load theory by Lavie (2004), under low perceptual load, more attentional resources are available to process irrelevant images in the periphery, whereas under high perceptual load, there are lessresources left for the processing of irrelevant images. Forster and Lavie (2008) found more attentional capture effects under low perceptual load than under high load, which is consistent with load theory. In the studies here, however, more attentional capture effects were found under high perceptual load than under low load.

As discussed in Experiment 3B, there are two major differences in experiment design between these two sets of studies: the ratio of attentional capture trials (33.33% here vs. 20% in theirs) and the duration of search display (200ms here vs. 100ms in theirs). The short duration of search display was to prevent eye-movements when searching for a target. It is relatively unlikely that increasing the duration from 100ms to 200ms would create the exact opposite pattern of capture effects. However, the ratio of capture trials could possibly be an important factor. Cosman and Vecera (2010) found that the frequency of the onsets affected attentional capture effects under high perceptual load. Specifically, frequently presented onsets did not capture attention under high load, whereas infrequent onsets had robust capture effects. Unfortunately, the results in this dissertation cannot be well explained by Cosman and Vecera (2010), because the studies here with more frequent capture stimuli actually revealed larger attentional capture effects under high load, compared to Forster and Lavie (2008), whereas relatively infrequent capture stimuli revealed smaller capture effects under high load. However, Cosman and Vecera (2010) does still suggest that the ratio of the attentional-capture stimuli could be an important factor to modulate the capture effects. The author and colleagues are currently conducting some follow-up studies to investigate whether the ratio of capture trials could be a possible explanation for the opposite pattern of attention capture effects.

4.5 Summary

Taken together, the results of this dissertation demonstrate that high outcome pressure disrupts selective attention under high load for the non-emotional stimuli of letters. The effects are robust and replicated in all three letter experiments. In contrast, high outcome pressure does not affect selective attention for the emotional stimuli of emoticons. In terms of task-relevance of distractors, only the task-relevant distractors interact with pressure effects under load, whereas the task-irrelevant distractors are immune to pressure effects.

CHAPTER 5 FIGURES AND TABLES

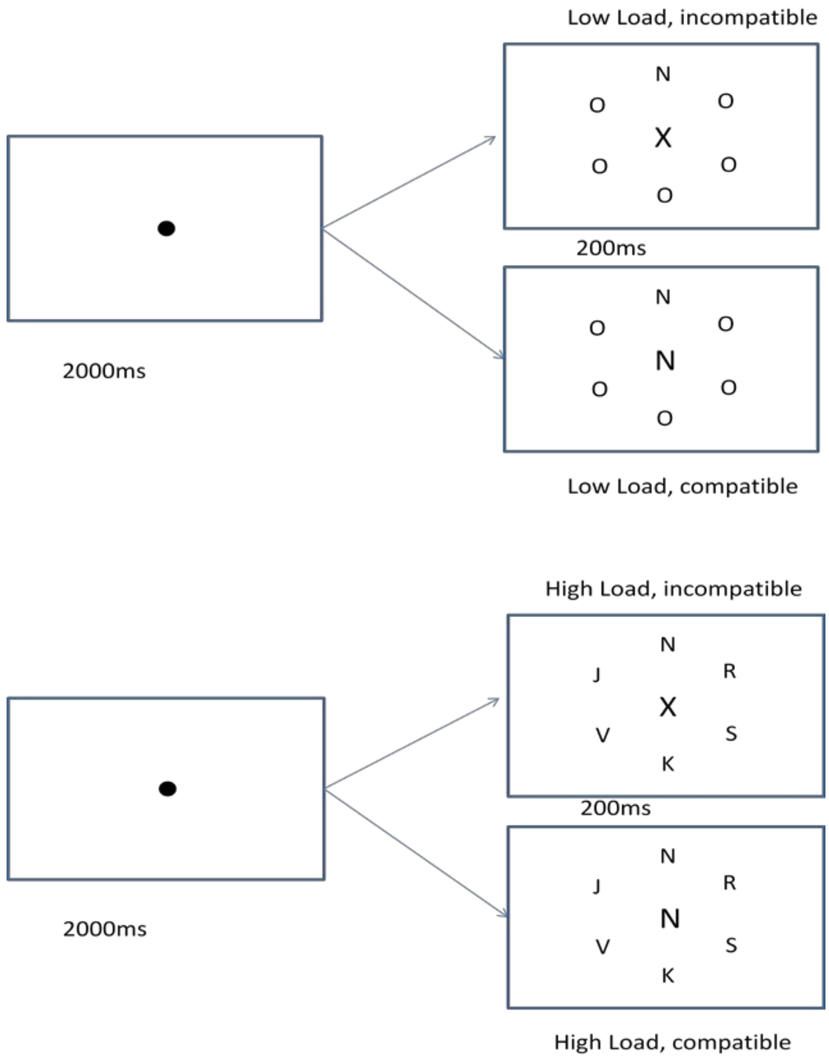


Figure 1: The trial procedure for Experiment 1. Participants were asked to search for a letter X or N in the circle while ignoring the letter in the center. The top part is for low perceptual load conditions and the bottom part is for high perceptual load conditions.

Table 1: Mean scores for STAI-state across all four experiments in the pretest and posttest for the two groups. Larger score values indicate higher anxiety levels.

	Experiment 1		Experiment 2		Experiment 3		Experiment 4	
Group	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Control	32.4 (8.1)	32.7 (10.0)	31.8 (10.6)	32.4 (9.7)	32.7 (9.4)	34.9 (9.8)	34.9 (11.9)	35.5 (9.3)
Pressure	31.3 (8.8)	41.6 (11.7)	36.2 (7.3)	46.4 (9.7)	34.6 (10.8)	41.7 (12.6)	30.1 (7.0)	36.1 (10.9)

Table 2: Experiment 1, Mean reaction times (ms) across participants (N = 17 and 18, respectively) as a function of pre/posttest, load and compatibility for the two groups.

	Pretest				Posttest			
	Low load		High load		Low load		High load	
Group	I	C	I	C	I	C	I	C
Control	652 (101)	579 (89)	804 (148)	767 (102)	622 (100)	562 (98)	758 (117)	752 (120)
Pressure	690 (145)	616 (111)	852 (184)	815 (182)	598 (103)	528 (88)	743 (140)	687 (126)

Note: I = Incompatible; C = Compatible;

Table 3: Experiment 1, Flanker effect (Incompatible - Compatible) across participants (N = 17 and 18, respectively) as a function of pre/posttest and load for the two groups.

	Pretest		Posttest	
Group	Low load	High load	Low load	High load
Control	73 (43)	37 (80)	59 (35)	6 (40)
Outcome Pressure	74 (44)	37 (58)	70 (32)	55 (57)

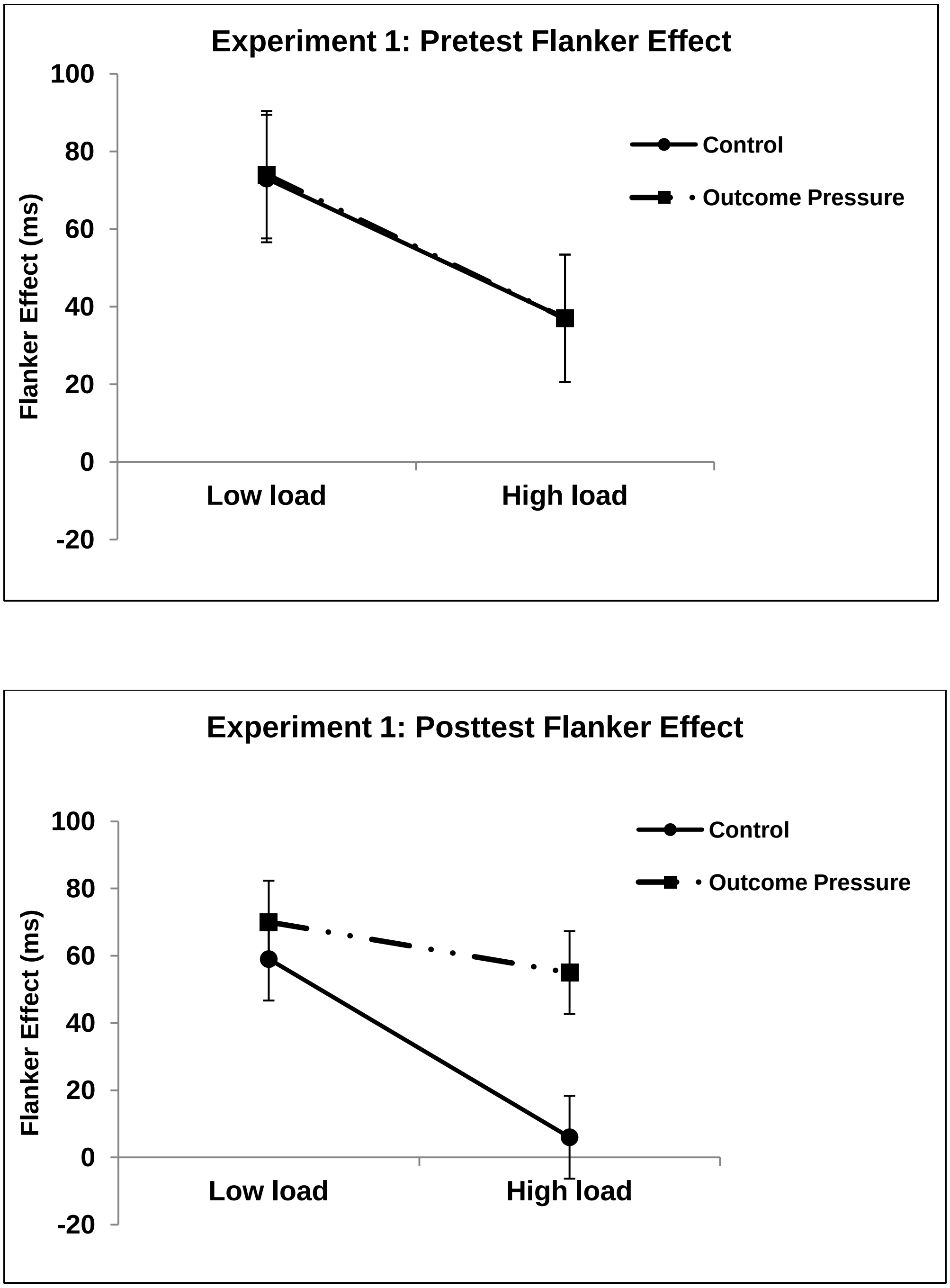


Figure 2: Experiment 1, Flanker effect (Incompatible- Compatible) as a function of perceptual load for the two groups, for the pretest (top panel) and posttest sessions (bottom panel), respectively. Error bars represent 95% CIs for each data point. For the pre-test session, only the main effect of load is significant and all other possible main effects and interactions are not significant. For the post-test session, there is an interaction between group and load, and a main effect of group.

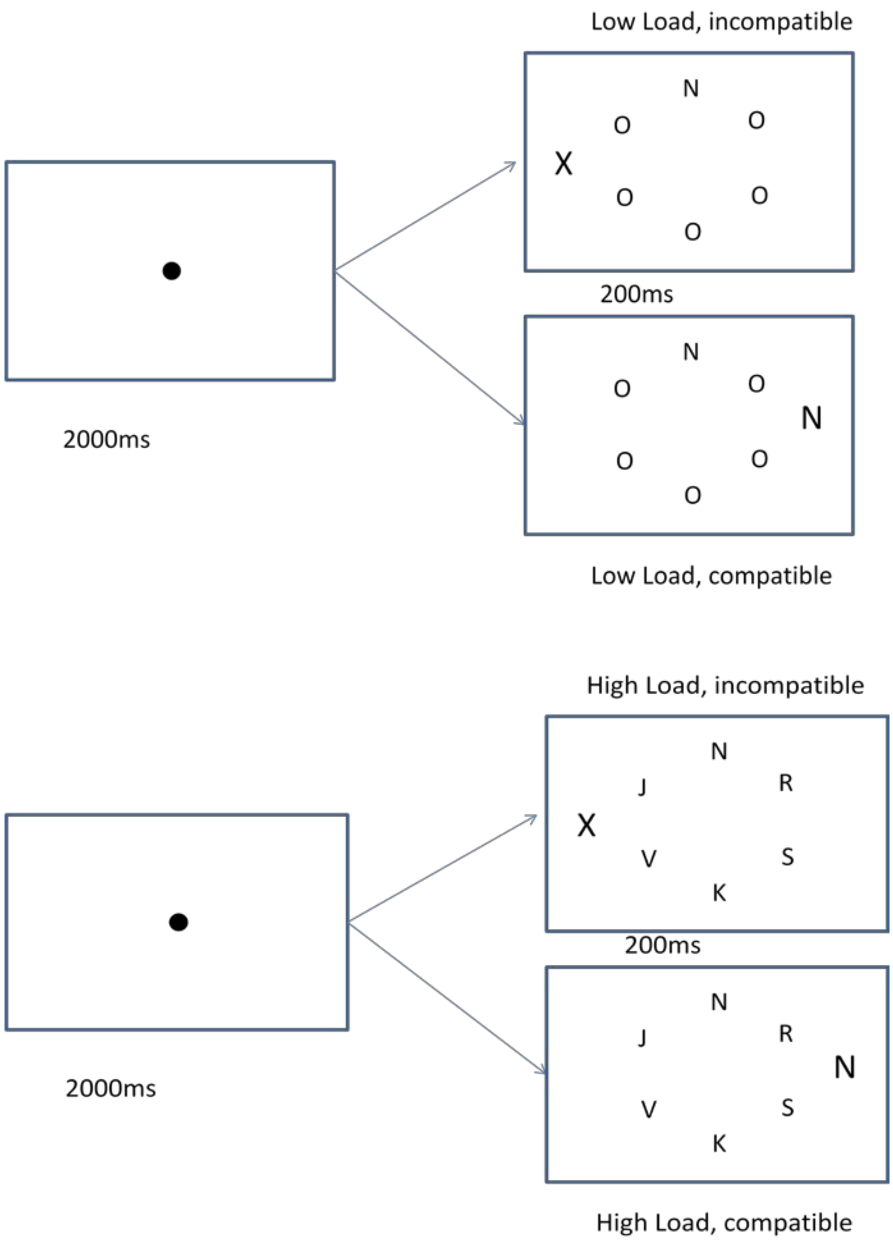


Figure 3: The trial procedure for Experiment 2. The peripheral distractor could be either on the left or right side. The task was to search for a letter X or N in the circle while ignoring the letter on the side.

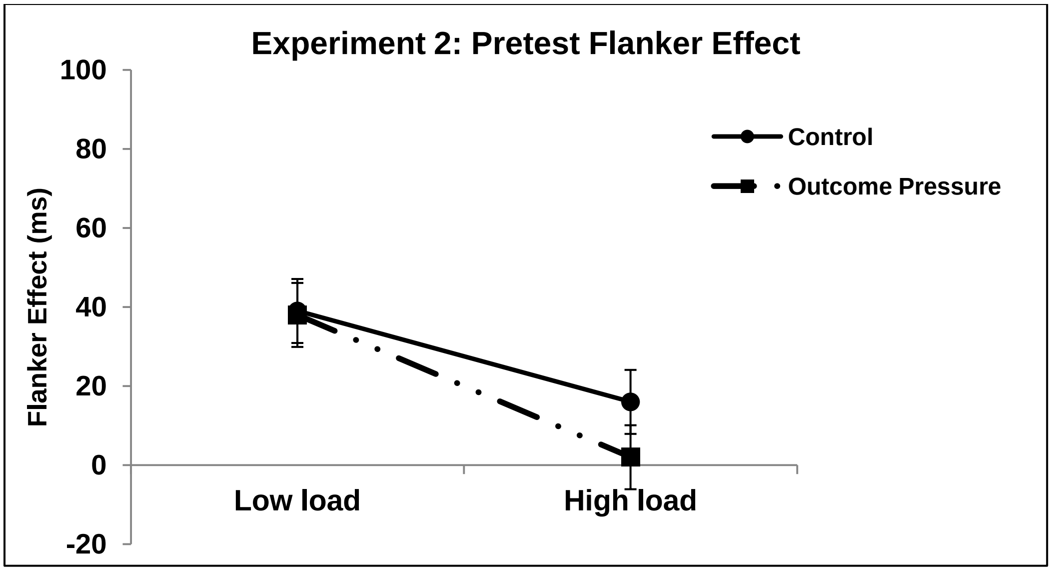
Table 4: Experiment 2, Mean Reaction times (ms) across participants (N = 19 for each group) as a function of pre/posttest, load, and compatibility for the two groups.

	Pre-test				Post-test			
	Low load		High load		Low load		High load	
Group	I	C	I	C	I	C	I	C
Control	584 (96)	545 (93)	743 (137)	727 (129)	565 (101)	542 (106)	705 (118)	711 (133)
Pressure	576 (119)	538 (100)	707 (126)	705 (106)	525 (90)	501 (80)	672 (119)	646 (91)

Note: I = Incompatible; C = Compatible;

Table 5: Experiment 2, Flanker effect (Incompatible - Compatible) across participants (N=19 for each group) as a function of pre/posttest, and load for the control group using subject pool participants.

	Pre-test		Post-test	
Group	Low load	High load	Low load	High load
Control	39 (24)	16 (41)	23 (25)	-6 (44)
Pressure	38 (32)	2 (39)	24 (26)	26 (40)



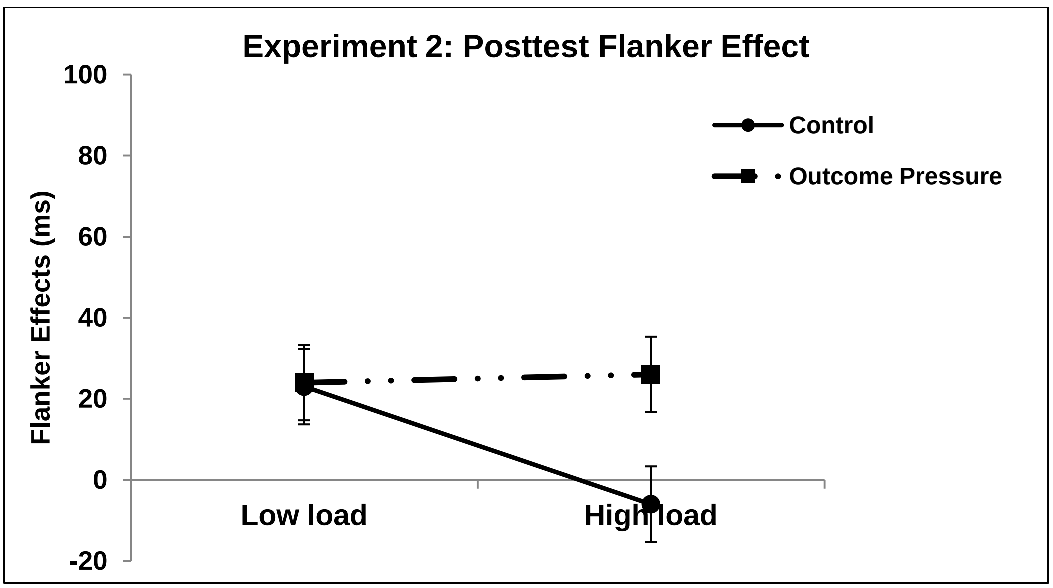


Figure 4: Experiment 2, Flanker effect (Incompatible- Compatible) as a function of perceptual load for the two groups during the pretest (top) and posttest sessions (bottom). Error bars represent 95% CIs for each data point. For the pre-test session, there was no interaction between group and load, and no main effect of group. However, there was a significant main effect of load. For the post-test session, there was an interaction between group and load, and a significant main effect of load.

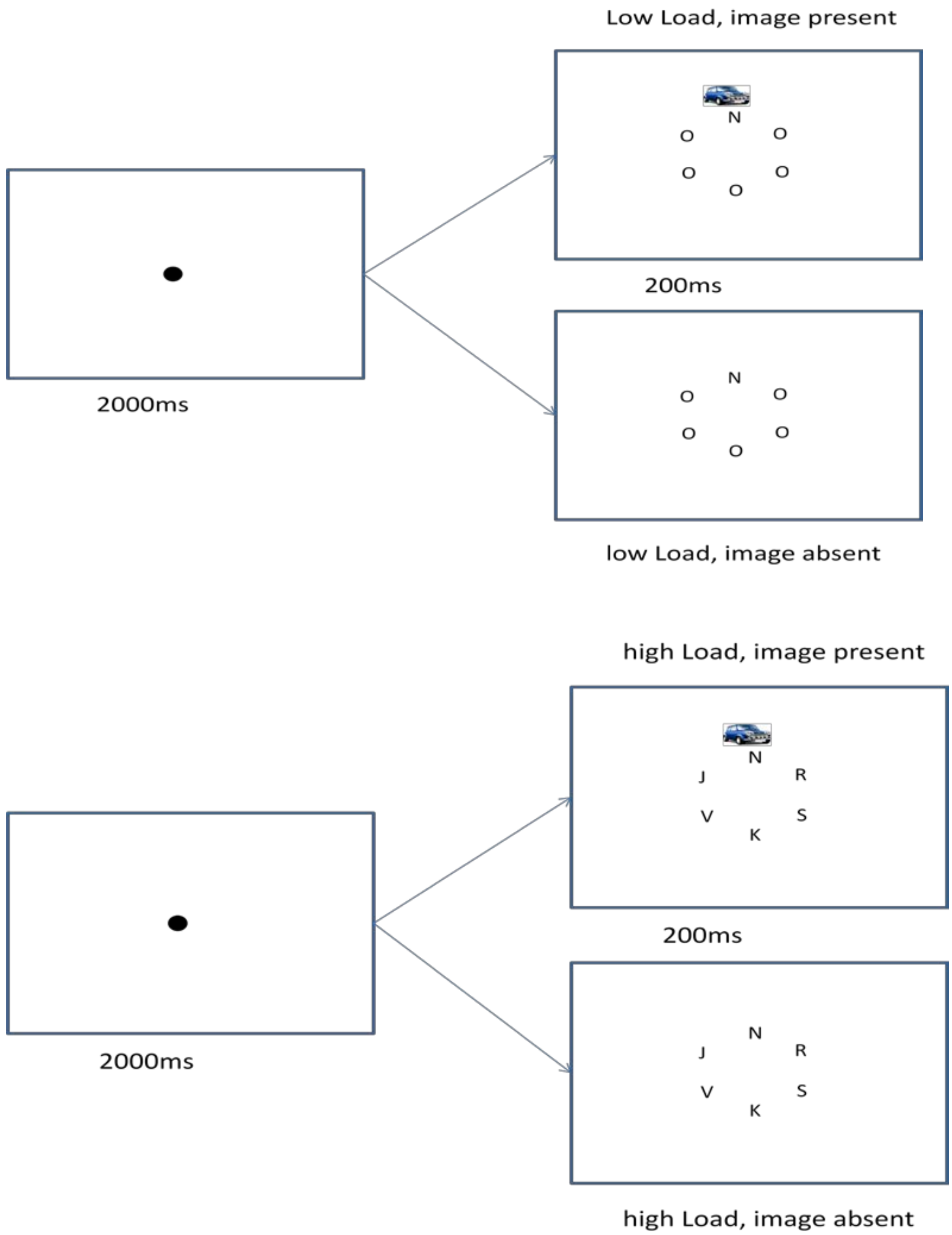


Figure 5. The trial procedure for attentional capture trials (the first two) and flanker trials (the second two on next page) in Experiment 3. The flanker trials in Experiment 3 are the same as in Experiment 2. Flanker trials (192 trials in each block) and attentional capture trials (96 trials) are mixed together.

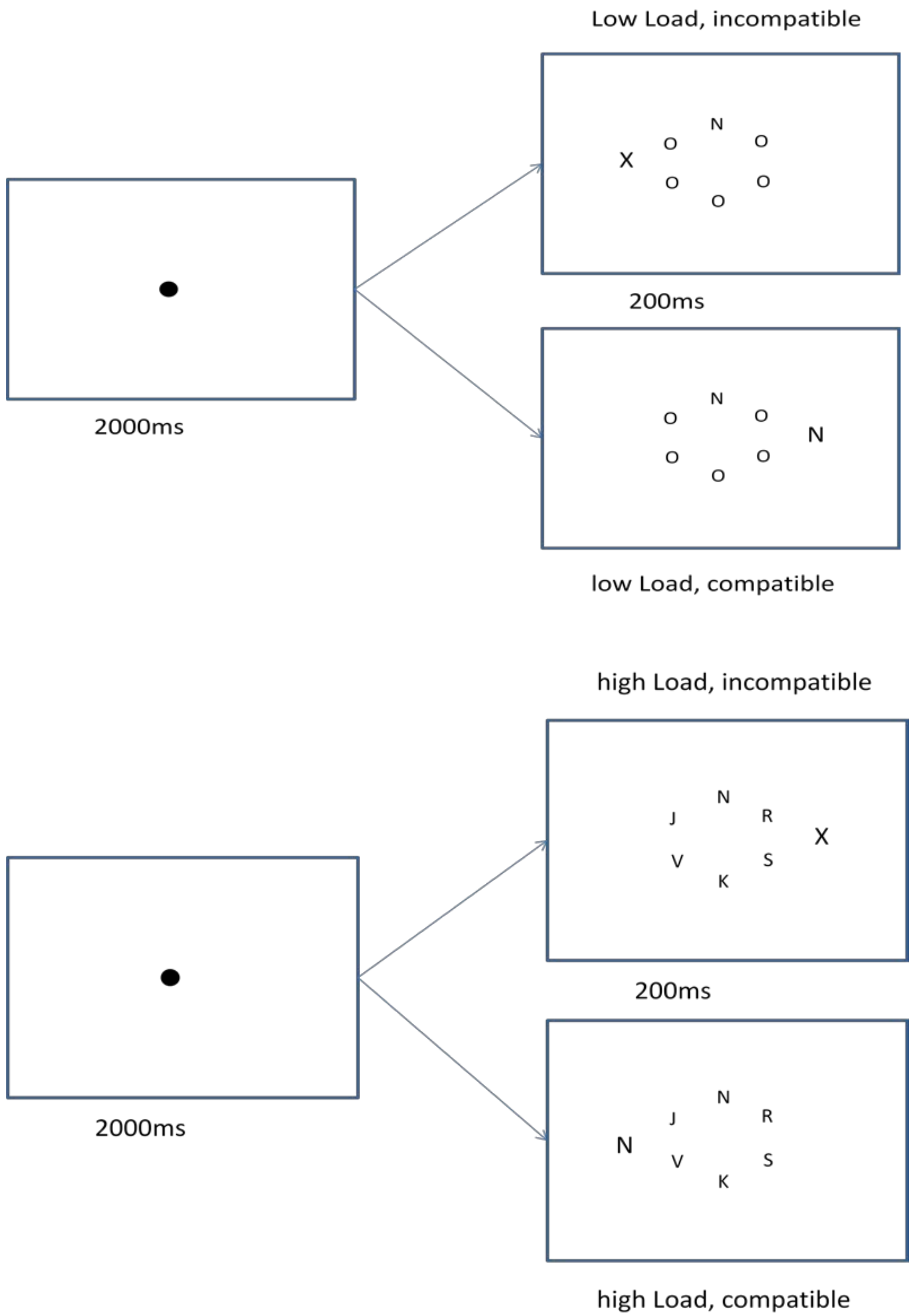


Figure 5 continued.

Figure 6: Experiment 3, the six possible images for attentional capture trials: cube, car, fan, flowers, shoes, and vegetables.

Table 6: Experiment 3, Mean reaction times (ms) for flanker trials across participants as a function of pre/posttest, perceptual load, and compatibility for two groups (N= 18 for each group).

	Pretest				Posttest			
	Low		High		Low		High	
Group	I	C	I	C	I	C	I	C
Control	574 (71)	536 (75)	732 (126)	716 (147)	562 (63)	533 (70)	706 (101)	712 (120)
Pressure	604 (88)	559 (75)	746 (98)	728 (94)	539 (70)	499 (68)	685 (115)	651 (100)

Note: I = Incompatible; C = Compatible;

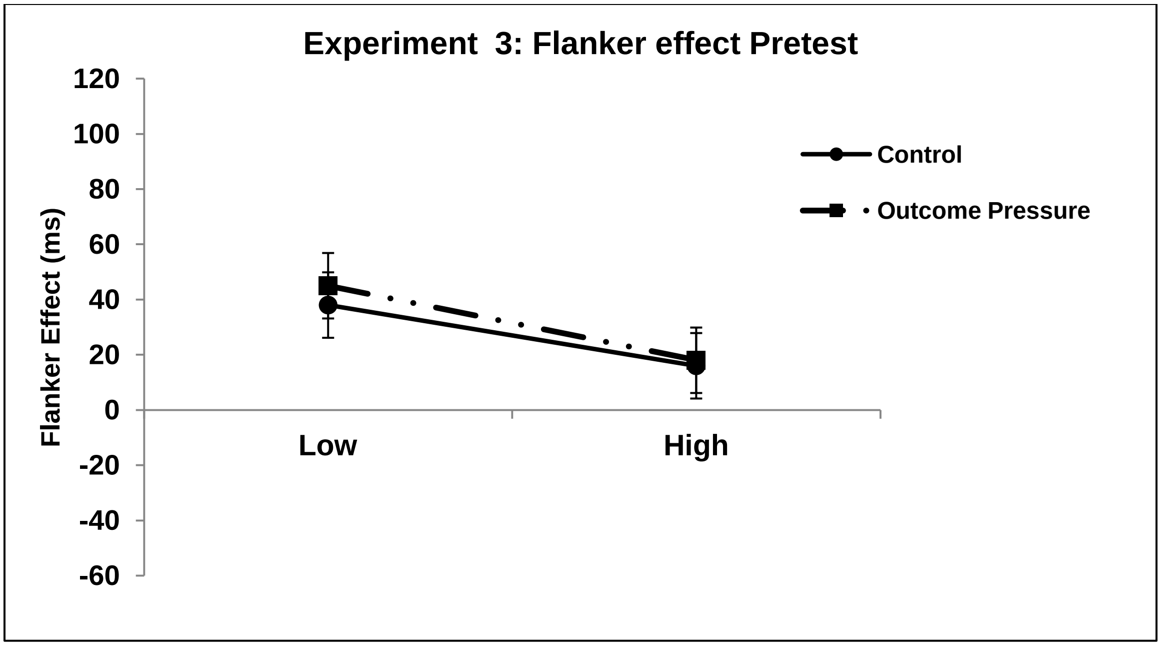
Table 7: Experiment 3, Mean reaction times (ms) for attentional capture trials across participants as a function of pre/posttest, perceptual load, and image presence for two groups (N=18 for each group).

	Pretest				Posttest			
	Low		High		Low		High	
Group	IP	IA	IP	IA	IP	IA	IP	IA
Control	548 (83)	529 (74)	748 (192)	693 (127)	547 (86)	524 (70)	715 (122)	702 (118)
Pressure	567 (65)	544 (63)	805 (132)	708 (100)	520 (70)	493 (69)	702 (114)	655 (115)

Note: IP = Image Present; IA = Image Absent;

Table 8: Experiment 3, Flanker effect (Incompatible - Compatible) and attentional capture effect (Image Present – Image Absent) across participants as a function of pre/posttest and perceptual load for two groups.

	Pretest				Posttest			
	Flanker effect		Attentional capture		Flanker effect		Attentional capture	
Group	low	high	low	high	low	high	low	high
Control	38 (20)	16 (64)	19 (44)	55 (83)	28 (26)	-6 (34)	23 (42)	12 (57)
Pressure	45 (35)	18 (58)	23 (44)	97 (83)	40 (27)	34 (48)	27 (21)	47 (59)



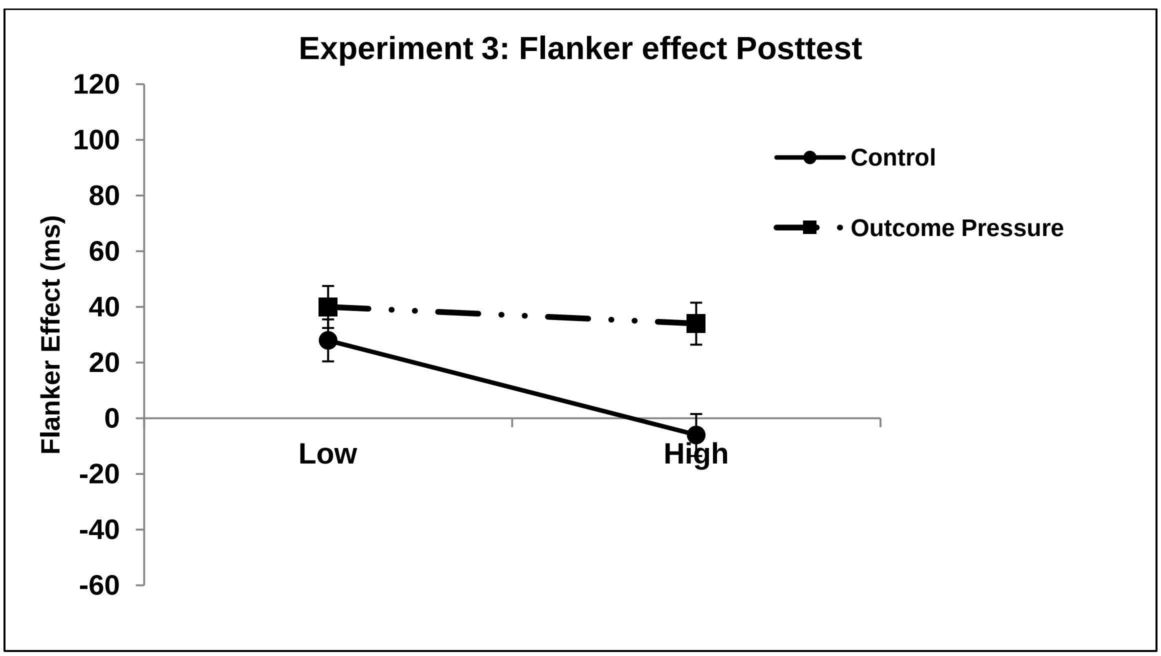
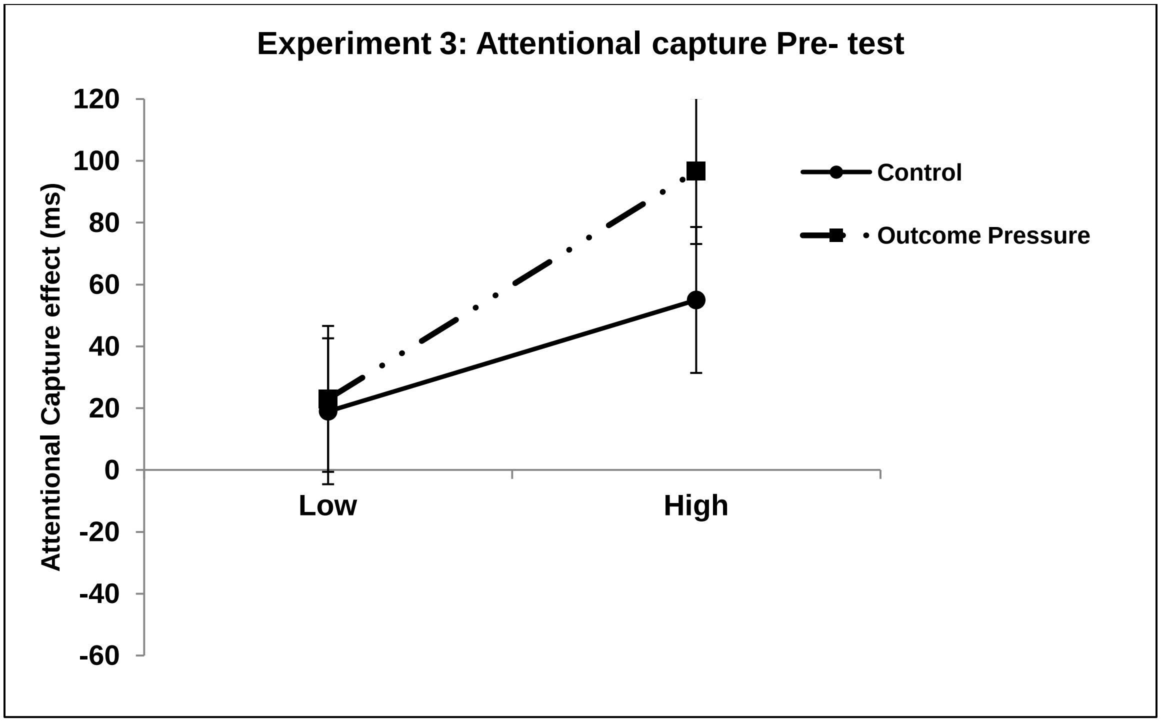


Figure 7: Experiment 3, Flanker effect (Incompatible- Compatible) as a function of perceptual load for the two groups, during the pre-test session (top) and the post-test session (bottom). Error bars represent 95% CIs for each data point.



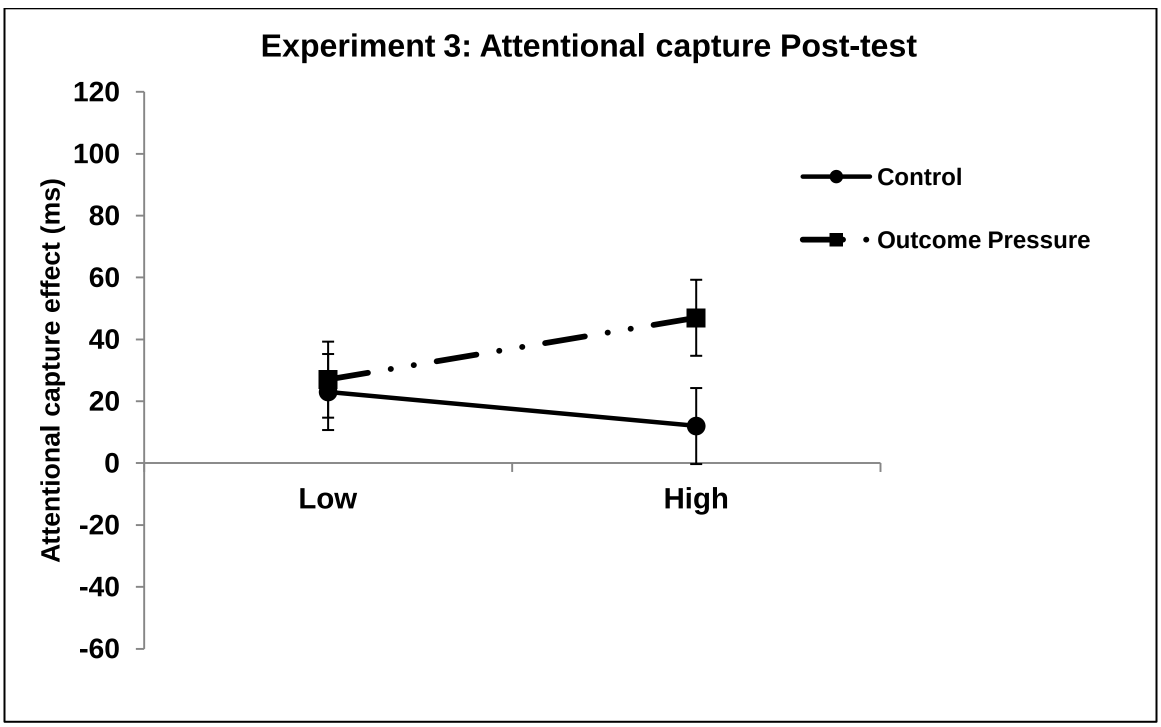


Figure 8: Experiment 3, Attentional capture effect (Image Present- Image Absent) as a function of perceptual load for the two groups, during the pre-test session (top) and the post-test session (bottom). Error bars represent 95% CIs for each data point.

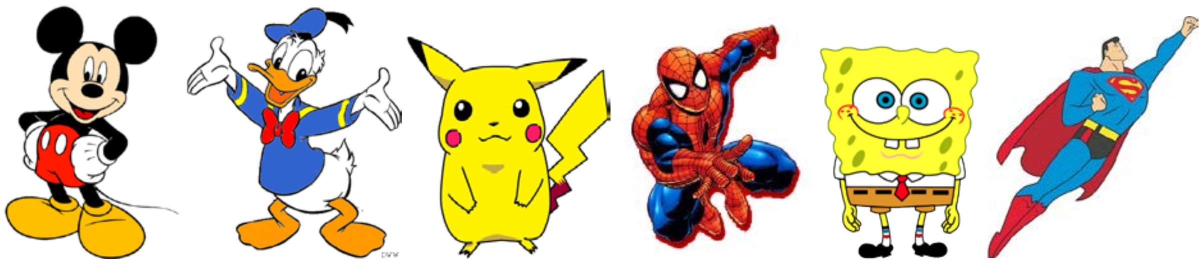


Figure 9: Experiment 3B, the six possible images for attentional capture trials: Mickey Mouse, Donald Duck, Pikachu, Spiderman, Sponge Bob, and Superman.

Table 9: Experiment 3B, Mean reaction times (ms) for flanker trials and attentional capture trials across participants as a function of load and compatibility or image presence in each block (N= 16 for each group).

	Low		High		Low		High	
Block	I	C	I	C	IP	IA	IP	IA
Block 1	597 (96)	554 (83)	755 (116)	734 (102)	600 (94)	557 (101)	800 (148)	723 (127)
Block 2	571 (84)	545 (104)	720 (108)	712 (123)	553 (101)	536 (86)	708 (112)	673 (112)

Note: I = Incompatible; C = Compatible; IP = Image Present; IA = Image Absent;

Table 10: Experiment 3B, Flanker effect (Incompatible - Compatible) and attentional capture effect (Image Present – Image Absent) across participants as a function of perceptual load in each block (N=16 for each group).

	Flanker effect		Attentional capture	
Block	low	high	low	high
Block 1	43 (34)	20 (46)	43 (30)	77 (61)
Block 2	26 (43)	9 (47)	17 (46)	35 (62)

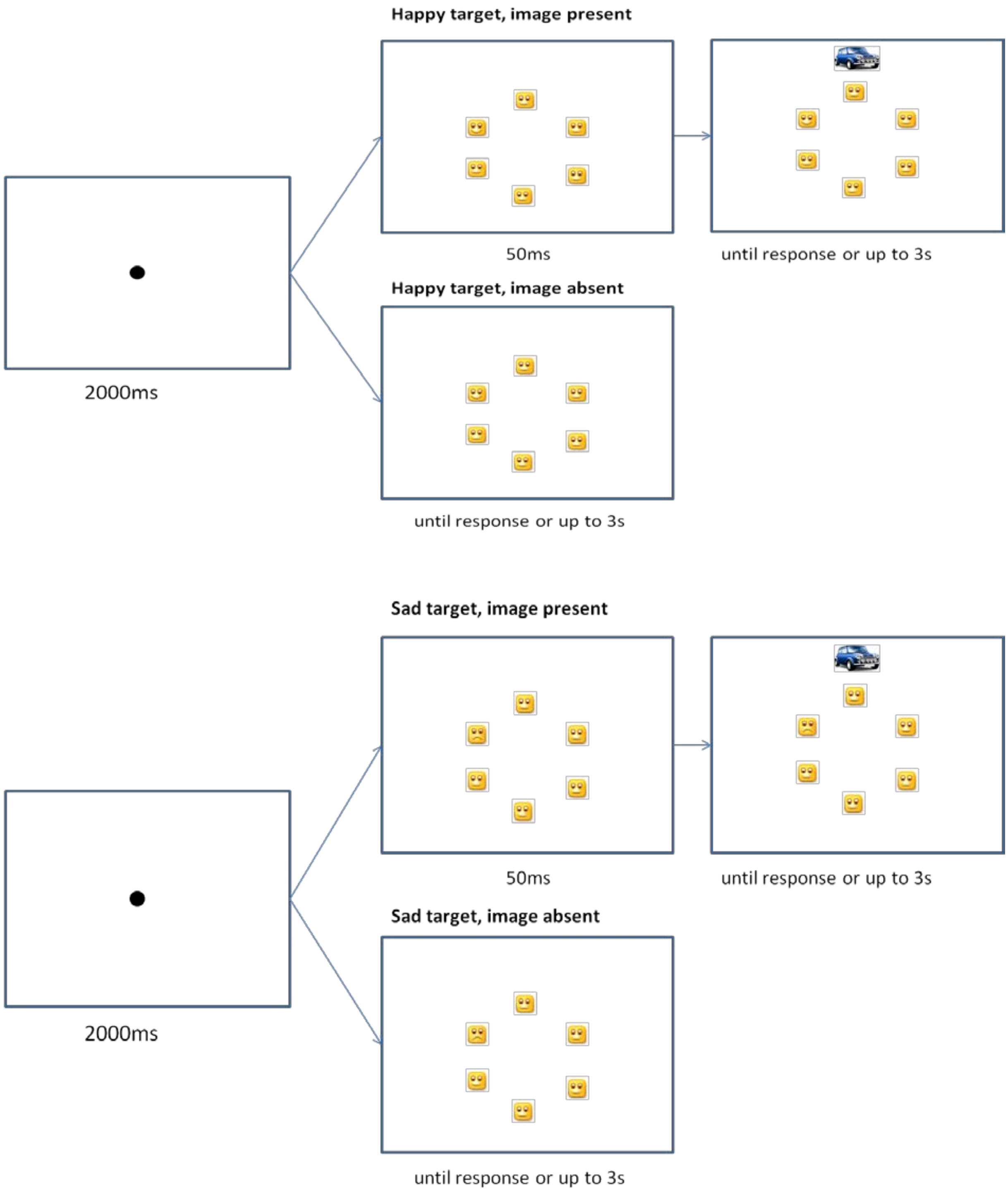


Figure 10: Attentional capture trials. Images appear on the top or on the bottom (2.8 to 3.2 degrees to the center) 50ms after onset of search display. Participants are to search for a non-neutral emoticon in the circle.

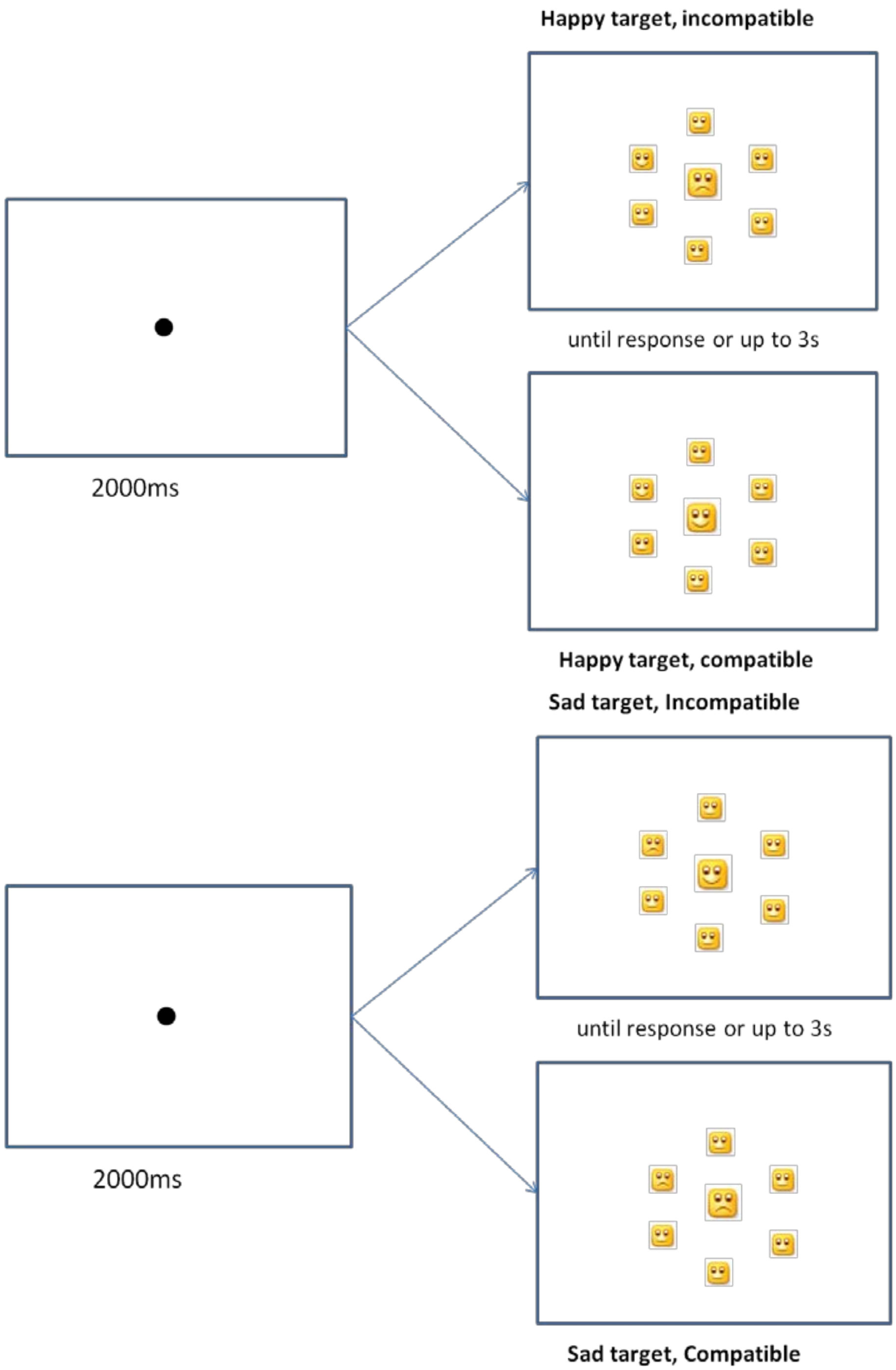


Figure 11: Experiment 4, flanker trials. Participants are supposed to search for a non-neutral emotion on the circle while ignoring the center emoticon. All flanker trials are mixed together with attentional capture trials.

Table 11: Experiment 4, Mean reaction times (ms) for flanker trials across participants as a function of pre/posttest, target emotional valence, and compatibility for the two groups (N=21 for each group).

	Pretest				Posttest			
	Happy		Sad		Happy		Sad	
Group	I	C	I	C	I	C	I	C
Control	1007 (122)	946 (139)	870 (176)	878 (143)	894 (117)	833 (125)	773 (122)	722 (105)
Pressure	966 (190)	891 (184)	812 (131)	847 (148)	852 (144)	790 (144)	715 (106)	715 (107)

Note: I = Incompatible; C = Compatible;

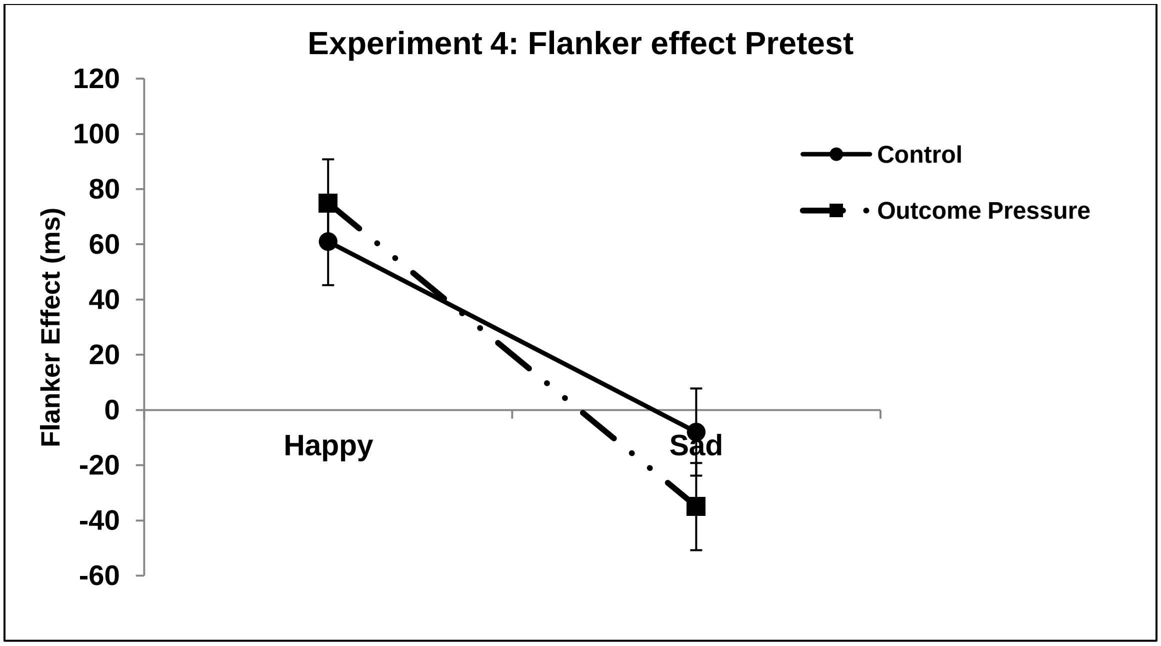
Table 12: Experiment 4, Mean reaction times (ms) for attentional capture trials across participants as a function of pre/posttest, target emotional valence, and image presence for the two groups (N=21 for each group).

	Pretest				Posttest			
	Happy		Sad		Happy		Sad	
Group	IP	IA	IP	IA	IP	IA	IP	IA
Control	966 (137)	870 (118)	847 (142)	805 (118)	799 (103)	801 (110)	735 (126)	727 (103)
Pressure	954 (167)	868 (169)	791 (149)	771 (133)	760 (150)	744 (152)	687 (111)	673 (100)

Note: IP = Image Present; IA = Image Absent;

Table 13: Experiment 4, Flanker effect (Incompatible - Compatible) and attentional capture effect (Image Present – Image Absent) across participants as a function of pre/posttest and target emotional valence for the two groups.

	Pretest				Posttest			
	Flanker effect		Attentional capture		Flanker effect		Attentional capture	
Group	happy	sad	happy	sad	happy	sad	happy	sad
Control	61 (70)	neg8 (61)	95 (110)	42 (78)	61 (71)	1 (47)	-2 (75)	9 (69)
Pressure	75 (55)	neg35 (67)	86 (105)	20 (89)	62 (45)	0 (34)	16 (100)	14 (49)



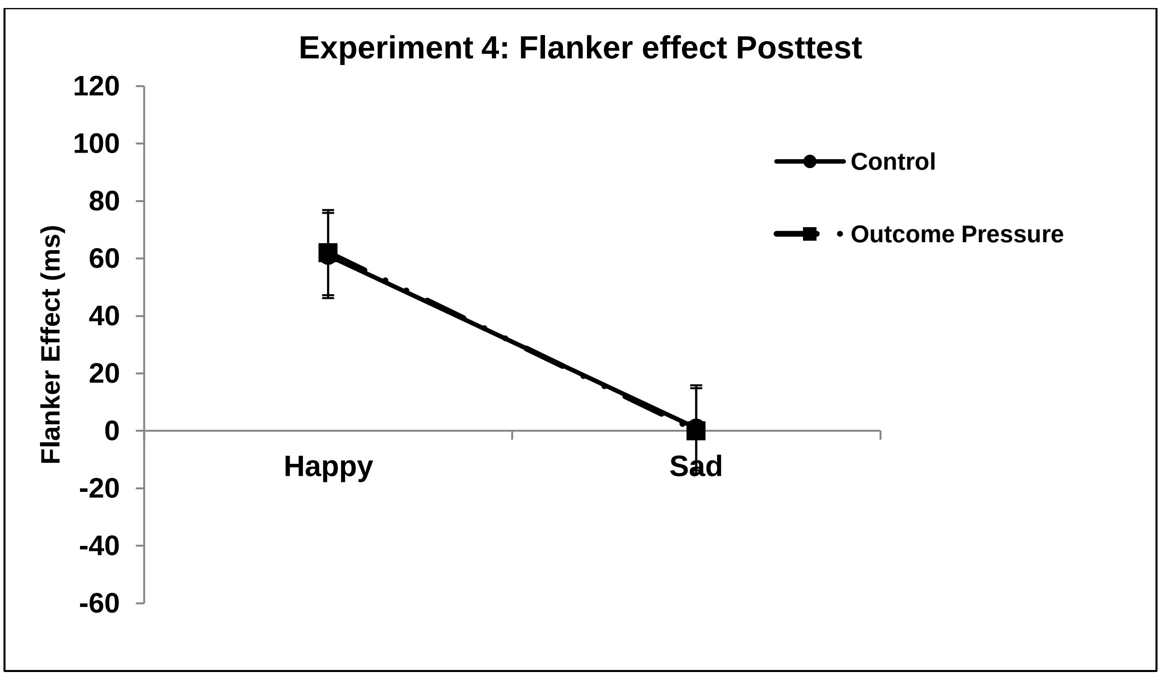
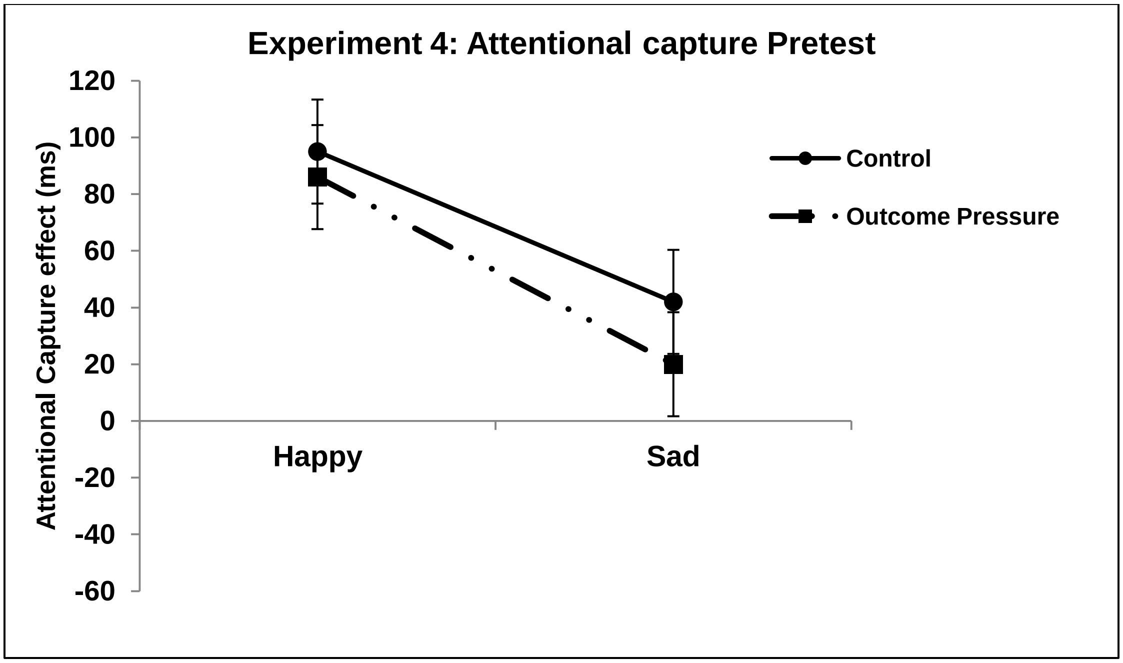


Figure 12: Experiment 4, Flanker effect (Incompatible - Compatible) as a function of target emotional valence for two groups, during the pretest session (top) and the posttest session (bottom). Error bars represent 95% CIs for each data point. For both pretest and posttest sessions, there was no interaction between group and target emotional valence, and no main effect of group. However, there was a significant main effect of target emotional valence both during the pretest and posttest.



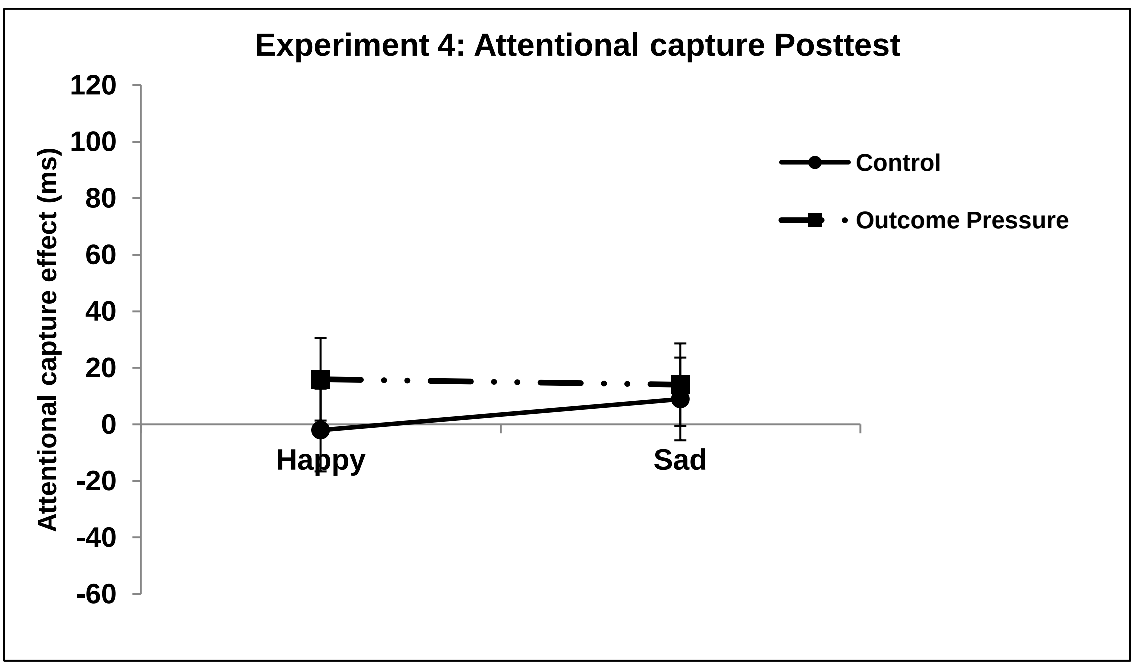


Figure 13: Experiment 4, Attentional capture effect (Image Present- Image Absent) as a function of target emotional valence for the two groups, during the pretest session (top) and the posttest session (bottom). Error bars represent 95% CIs for each data point. For both pretest and posttest sessions, there was no interaction between group and target emotional valence, and no main effect of group. However, there was a significant main effect of emotional valence in the pretest session, but this effect was absent in the posttest.

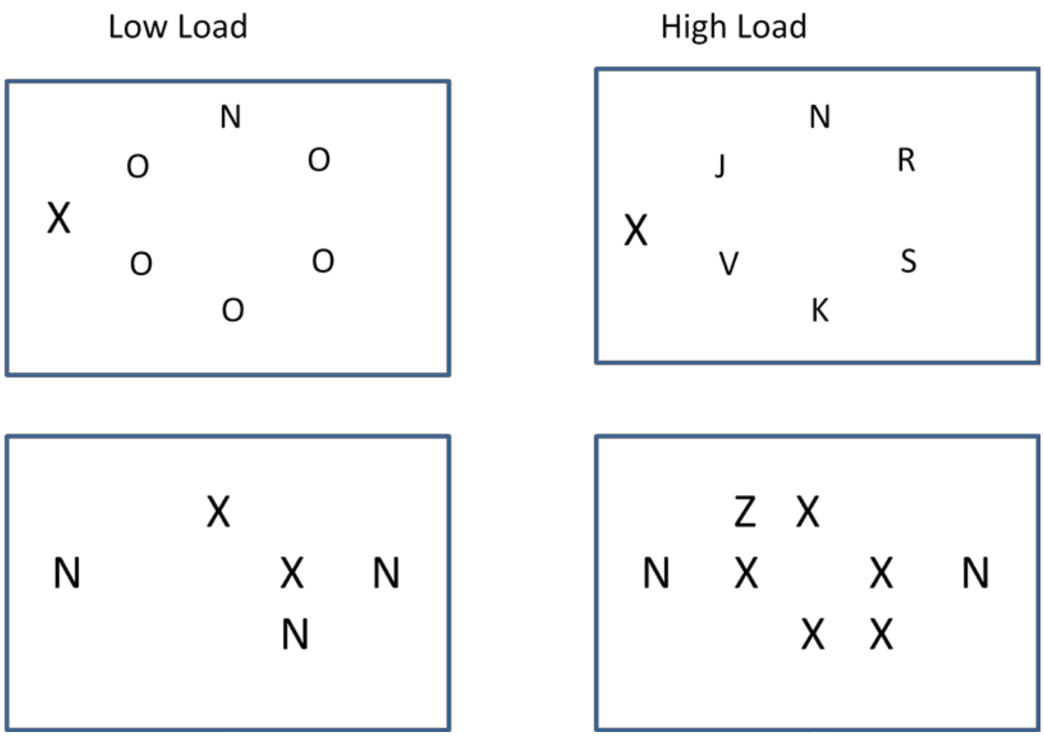


Figure 14: Schematic representation of the search displays in this study (the top row) and Sato et al (2012) (the bottom row). Note that in the top row, the task is to find N or X on the circle and ignore the letter on the side (either left or right). And on the bottom row, the task is to find N or Z in the center area and ignore the letter in the periphery. The left panel is for low load condition in both studies, and the right panel is for high load condition. On the top row (i.e., the current study), the radius of the circular search array is 2 degree. The flanker letter is 0.67 degree vertically, and non-target & target letters are 0.54 degree vertically. On the bottom row (i.e., Sato et al, 2012), all letters are 1 degree vertically, but it is unclear of the distance between the flanker and center target columns.

REFERENCES

Baddeley, A.D. (2000). "The episodic buffer: a new component of working memory?". *Trends in Cognitive Science* **4**: 417–423.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. Journal of Personality & Social Psychology, 46, 610-620.

Beck, D. M., & Lavie, N. (2005). Look here but ignore what you see: Effects of distractors at fixation. Journal of Experimental Psychology: Human Perception and Performance, 31 (3), 592-607.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? Journal of Experimental Psychology: General, 130, 701-725.

Beilock, S. L., & Carr, T. H. (2005).When high-powered people fail: Working memory and "choking under pressure" in math. Psychological Science, 16, 101-105.

Beilock, S. L., & DeCaro, M. S. (2007). From poor performance to success under stress: Working memory, strategy selection, and mathematical problem solving under pressure. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33, 983–998.

Beilock, S. L. (2008). Math performance in stressful situations. Current Directions in Psychological Science, 17, 339–343.

Belopolsky, A. V., Zwaan, L., Theeuwes, J., & Kramer, A. F. (2007). The size of an attentional window modulates attentional capture by color singletons. *Psychonomic Bulletin & Review*, 14 (5), 934 – 938.

Bradley, B.P., Mogg, K., Millar, N., Bonham-Carter, C., Fergusson, E., Jenkins, J., & Parr, M. (1997). Attentional biases for emotional faces. *Cognition and Emotion*, *11*, 25–42.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision* 10:433-436.

Carver, C. S., &Scheier, M. F. (1978).Self-focusing effects of dispositional self-consciousness, mirror, presence, and audience presence. *Journal of Personality and Social Psychology, 36,* 324–332.

Cohen, Y., Lachenmyer, J. R., & Springer, C. (2003). Anxiety and selective attention in obsessive-compulsive disorder. Behavior Research and Therapy. 41 (11), 1311-1323.

Cosman, J. D., & Vecera, S. P. (2010). Attentional capture under high perceptual load. Psychnomic Bulletin & Review, 17 (6), 815-820.

Cowan, N. (1995). Attention and memory. Oxford, England: Oxford University Press.

Cowan, N. (1999). An embedded-process model of working memory. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 62–101). Cambridge,England: Cambridge University Press.

Chu, H., Todd, J.J., Beilock, S., &Lleras, A. (2010). Endogenous attentional control “chokes” under pressure. Vision Sciences Society, Naples, FL.

DeCaro M. S., Thomas R. D., Albert N. B., Beilock S. L. (2011). Choking under pressure: multiple routes to skill failure. Journal of Experimental Psychology: General. 140, 390–406

Eastwood, J. D., Smilek, D., &Merikle, P. M. (2001).Differential attentional guidance by unattended faces expressing positive and negative emotion. Perception & Psychophysics, 63, 1004–1013.

Eastwood, J. D., Smilek, D., &Merikle, P. M. (2003). Negative facial expression captures attention and disrupts performance. Perception &Psychophysics, 65, 352–358.

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

Eriksen, B. A., &Eriksen, C. W. (1974).Effects of noise letters upon the identification of a target letter in a non-search task. Perception and Psychophysics, 16, 143-149

Fenske, M.J., & Eastwood, J.D. (2003). Modulation of focused attention by faces expressing emotion: Evidence from flanker tasks. Emotion, 3(4), 327-343.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. Journal of Experimental Psychology: Human Perception and Performance, 18, 1030−1044.

Forster, S., & Lavie, N. (2008). Failures to ignore entirely irrelevant distractors: The role of load. Journal of Experimental Psychology: Applied, 14 (1), 73-83.

Fountoulakis, K.N, Papadopoulou, M., Kleanthous, S., Papadopoulou, A., Bizeli, V., et al (2003). Reliability and psychometric properties of the Greek translation of the State-Trait Anxiety Inventory form Y: preliminary data. Annals of General Psychiatry. 5, 1-5.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. Cognition and Emotion, 16, 355–379.

Geller, V., & Shaver, P. (1976).Cognitive consequences of self-awareness. *Journal of Experimental Social Psychology, 12,* 99–108.

Gibson, B. S., & Kelsey, E. M. (1998). Stimulus-driven attentional capture is contingent on attentional set for displaywide visual features. Journal of Experimental Psychology: Human Perception and Performance, 24, 699−706.

Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking, and slumps. *Journal of Experimental Psychology: Applied, 10,* 42–54.

Hardy, L., Mullen, R., & Jones, G. (1996). Knowledge and conscious control of motor actions under stress. *British Journal of Psychology, 87,*621-636.

Hockey, G. R. J. (1970a). Effect of loud noise on attentional selectivity. *Quarterly Journal of Experimental Psychology*, 22, 28-36.

Hockey, G. R. J. (1970b). Signal probability and spatial location as possible bases for increased selectivity. *Quarterly Journal of Experimental Psychology*, 22, 37-42.

Horstmann, G., Borgstedt, K. &Heumann, M. (2006). Flanker effects with faces may depend on perceptual as well as emotional differences. Emotion, 6, 28-39

Langton, S.R., Law, A.S., Burton, A.M., & Schweinberger, S.R. (2008). Attention capture by faces. Cognition, 107 (1), 330-342.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. Journal of Experimental Psychology: Human Perception and Performance, 21, 451–468.

Lavie, N., & Cox, S. (1997). On the efficiency of attentional selection: Efficient visual search results in inefficient rejection of distraction. Psychological Science, 8, 395–398.

Lavie, N..Hirst, A., de Fockert, J. W., & Viding, E (2004).Load theory of selective attention and cognitive control. Journal of Experimental Psychology. 133 (3), 339–54.

Lawrence R. M. (2000). Is the finding of obsessional behaviour relevant to the differential diagnosis of vascular dementia of the Binswanger type? Behavioral Neurology. 12 (3), 149–54.

Lewis, B., & Linder, D. (1997). Thinking about choking? Attentional processes and paradoxical performance. *Personality and Social Psychology Bulletin, 23,* 937–944.

Liao, C.-M., & Masters, R. S. W. (2002). Self-focused attention and performance failure under psychological stress. Journal of Sport & Exercise Psychology, 24, 289-305.

Liston C, et al. (2006) Stress-induced alterations in prefrontal cortical dendritic morphology predict selective impairments in perceptual attentional set-shifting. Journal of Neuroscience, 26: 7870–7874.

Liston C, McEwen B.S, Casey B. J. (2009). Psychosocial stress reversibly disrupts prefrontal processing and attentional control. Proc Natl Acad Sci USA 106:912–917

Markman, A. B., Maddox, W. T., & Worthy, D. A. (2006). Choking and excelling under pressure. Psychological Science, 17, 944-948.

Mather, M., & Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychological Sciences.* 14 (5), 409-415.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision* 10:437-442.

Posner, M.I., (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*. 32, 3 –25.

Posner, M.I., Cohen, Y. (1984). Components of visual orienting. In: Bouma, H., Bouwhuis, D. (Eds.), Attention and Performance, vol. X. Lawrence Erlbaum, London, pp. 531–554.

Sato, H., Takenake, I., & Kawahara, J.I. (2012). The effects of acute stress and perceptual load on distractor interference. Quarterly Journal of Experimental Psychology. 65 (4), 617-623.

Spielberger C. D. (1976). The nature and measurement of anxiety. In Cross-cultural anxiety Edited by: (Eds.) CDSRDG. Washington, D. C., Hemisphere/Wiley.

Stein D. J. (2002). Obsessive-compulsive disorder. Lancet.360, 397-405.

Theeuwes, J., & Van der Stigchel, S. (2006). Faces capture attention: Evidence from inhibition of return. Visual Cognition, 13, 657–665.

Torralbo, A., & Beck, D. M. (2008).Perceptual-loadinduced selection as a result of local competitive interactions in visual cortex. *Psychological Science, 19*, 1045-1050.

Tsal, Y., & Benoni, H. (2010). Diluting the burden of load: Perceptual load effects are simply dilution effects. Journal of Experimental Psychology: Human Perception and Performance. 36 (6), 1645-1656.

Weissman M. M., Bland R. C., Canino G. J., et al (1994). The cross national epidemiology of obsessive compulsive disorder. Journal of Clinical Psychiatry. 55, 5–10.

Williams, L.J. (1988). Tunnel vision or general interference? Cognitive load and attentional bias are both important. The American Journal of Psychology, 101 (2), 171-191.

Wine, J. (1971). Test anxiety and direction of attention. Psychological Bulletin, 76, 92–104.

Yantis, S. and Jonides, J. (1990). Abrupt visual onsets and selective attention: voluntary versus automatic allocation. Journal of Experimental Psychology: Human Perception and Performance. 16, 121–134.