Neuroticism Related Differences during Processing of Controlled Cognitive Tasks

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DECLARATION

I hereby declare that this thesis has not been, and will not be submitted, in whole or in part to another University for the award of any other degree. One study (Chapters 6) presented in this thesis have been already published and two studies (chapter 2 and chapters 3-5) which are still in preparation to be submitted in the following journals:

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CONTENTS

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ABSTRACT

It is suggested that neuroticism impairs cognitive performance mostly in difficult tasks i.e. WM tasks, but not so much in easier tasks. However, behavioural, and functional neuroanatomical correlates of detrimental effect of neuroticism in relation to central executive system (CES) during cognitive tasks particularly in multitasking still unknown. I aim at investigating behavioural and functional neuroanatomical correlates of single- and dual-task performance in high and low neurotics. The general hypothesis is that high neurotics will show a poorer performance on processing of cognitive tasks as compared to low neurotics. From a screened population, I select low neurotics (below 6) and high neurotics (over 16) on 24 item Eysenck Personality Questionnaire (EPQ) neuroticism scale. First empirical study was consisted of three standard WM tests. The result of this study showed that high neurotics had lower performance when the task heavily requires CES such as switching and inhibition. Next empirical studies were consisted of dual tasks based on PRP paradigm. In dual task studies, in addition to SOA manipulation SOA (0 and1000ms), task demand manipulated either by presentation of task order or task set maintenance. The results show that high neurotics considerably slower when SOA is short. Further, it has been observed dual task cost differences between high and low neurotics increase as the demand increase either by random tasks or task set maintenance as evident by lower processing efficiency in high neurotics. Also, high neurotics perceived higher stress level as the task demand increase. In the final study, I assessed brain activity by means of functional magnetic resonance imaging (fMRI) in low and high neurotics while they were performing a demanding dual-task and the less demanding component tasks as single-tasks. Imaging data showed that high neurotics showed less dual-task specific activation in lateral and medial prefrontal cortices. In conclusion, I conclude that high levels of neuroticism impair behavioural performance in demanding tasks with higher perceived stress level, and that this impairment is accompanied by reduced activation of the task-associated brain areas.

Key words: Neuroticism, Personality, Multitasking, dual-task performance, prefrontal

cortex attentional control theory, working memory

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1 Chapter – Literature Review

1.1 Overview

Personality refers to characteristic patterns of behaviours, emotions and temperament and how these traits differ among individuals (Allport, 1961, p. 28; Engler, 2009). Therefore, people's perceptions, interpretations and reactions are guided by their personality traits (Allport, 1961, p. 28; Engler, 2009). One personality trait is neuroticism. It is one of the major personality traits and refers to emotional instability and an inclination to worry, as well as clinical anxiety and other psychological disorders (Eysenck, 1978). Because high neurotics are more anxious, they encounter more problems compared to low neurotics in their daily lives such as in the workplace or school (Eysenck & Cookson, 1969). For example, studies have shown that they are less successful regarding their maths skills, and more reactional when they encounter averse stimuli (i.e. during an argument) (Eysenck & Cookson, 1969), and in multitasking situations such as walking while talking (LeMonda, Mahoney, Verghese, & Holtzer, 2015). In the field of experimental psychology, these findings have led neuroticism to become one of the most widely investigated traits among the personality traits, generally during emotional tasks and latterly during cognitive tasks. Therefore, plenty of behavioural and neuroimaging studies can be found about the relationship between neuroticism and emotion (Canli et al., 2001; Eisenberger, Lieberman, & Satpute, 2005). However, the studies in relation to cognitive process and neuroticism are relatively few in number. Those empirical studies generally found out that high neurotics are negatively affected during the presentation of emotional images, videos etc. as compared to low neurotics (Canli et al., 2001; Eisenberger et al., 2005). The general results in terms of neuroticism and cognitive tasks can be interpreted as follows: high neurotics were observed to perform less well during working memory tasks such as an n-back task (Studer-Luethi, Jaeggi, Buschkuehl, & Perrig, 2012) and while multitasking (dual task: performing two tasks concurrently) (Corr, 2003; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). However, research on the detrimental effects of neuroticism in relation to working memory (WM), particularly during multitasking, is limited and somewhat inconclusive. For example, while it has been shown that high neurotics encounter interference in one experiment, in another experiment this result could not be confirmed (Corr, 2003; Szymura & Wodniecka, 2003). Importantly, the behavioural and neural association between components of working memory (i.e. executive functions and slave systems) and neuroticism is still unknown. Therefore, the broad aim of this thesis is to investigate neuroticism related differences during standard WM tasks and particularly PRP dual task processing. As neuroticism is one of the main precipitating factors of psychological disorders such as anxiety and depression, it is important to understand cognitive processing in high and low neurotics because this will contribute to the identification of treatments that can help to alleviate the cognitive deficits associated with neuroticism. Furthermore, it will contribute to a deeper understanding of the behavioural performance and neural correlation of the cognitive system.

I assessed neuroticism in a comprehensive manner to shed light upon neuroticism in relation to cognitive processing. Therefore, I utilized some reliable methods. Firstly, I used Cambridge Neuropsychological Test Battery (CANTAB) tasks, which include well standardized and validated working memory tests (SWM: spatial working memory test, IED: set shifting test, and SOC: stocking of Cambridge). While WM tasks have previously been used to investigate the general performance of high and low neurotics, Cantab tests were designed to measure specific working memory functions. Based on the literature, as a starting point, I selected three tests of Cantab, and using this group of WM tasks, I aimed to explore neuroticism related differences in relation to functions of the central executive system and the visuospatial component of WM. Furthermore, my investigation aims to provide deep insights into the cognitive system in high and low neurotics. Therefore, I decided to design a set of experiments that are mainly dual tasks.

There are several types of dual tasks and they are usually a combination of two WM tasks e.g (Baddeley, 1997; Baddeley, 1996a). Thus, while each WM task is performed as a single task, they are performed in rapid succession in dual tasks. For example, the literature shows that generally high neurotics are worse than low neurotics in dual task processing (Corr, 2003; Flehmig, Steinborn, Westhoff, & Langner, 2010; Szymura & Wodniecka, 2003). However, the results are rather inconclusive and it has not been determined where in cognitive processing the impairment occurs (Corr, 2003; Flehmig et al., 2010; Szymura & Wodniecka, 2003). One reason for that is that in those studies the dual task was usually a combination of two WM tasks and the researchers often measured the general performance in high and low neurotics. Thus, the researchers did not elaborate where the impairment occurred in high neurotics during dual task processing. Different from those dual tasks, one popular method is psychological refractory period (PRP) dual task paradigms. This is when two tasks are performed simultaneously or in close temporal proximity (Pashler, 1994a). The processing of the second task will be delayed until the processing of the first task has been completed (Pashler, 1994a). This delay is caused by a mental channel called a ‘bottleneck’ in the response selection stage because while the two tasks can be processed in parallel during the perception and motor stages, they can only be handled one at a time in the response selection stage (Pashler, 1994a). In addition to PRP's popularity in the field, this method allows for examining the results comprehensively (Szameitat, Schubert, Müller, & Von Cramon, 2002; Szameitat, Schubert, & Müller, 2011). Thus, I will be able to find out why and how the interference occurred during the task processing in high and low neurotics.

As this thesis is based on understanding neuroticism related differences during cognitive task processing, the review of the current literature consists of several sections. First, I present neuroticism and discuss neuroticism related traits. Second, I present a WM model and discuss the role of the WM components, particularly the central executive system. I present these two sections in advance because the next sections are about neuroticism related cognitive theories and empirical evidence. For a better understanding, the subsequent sections, firstly neuroticism and working memory should be understood. The subsequent chapters are empirical and focus on the processing of working memory tasks, mostly dual tasks in high and low neurotics. Each empirical chapter includes either behavioural or neuroimaging data collected from participants with high and low neurotics. The last chapter presents a general assessment of the results and the conclusion.

1.2 Understanding Personality and Neuroticism

This section provides information about definitions, and well-known models of personality in relation to neuroticism. Firstly, personality is defined and subsequently two models of personality, the Big three (H. J. Eysenck & Eysenck, 1975) and the Big five, (Costa & McCrae, 1985) and their measures are explained in a brief manner.

1.2.1 Personality

Personality is conceptualized in terms of individual distinctions including behavioural patterns, and emotional and cognitive activities (Engler, 2009; Engler, 2013; Mischel, Shoda, Smith, & Mischel, 2004). Thus, personality is usually described as typical behavioural patterns, affects and thoughts that are moderated by dominant personality features (Allport, 1961, p. 28; Engle 2009; Carver and Scheier 2000). There are various type of personalities and each type of personality can be called a personality trait (e.g. neuroticism or extraversion are different personality traits) (Allport, 1961; Carver, Sutton, & Scheier, 2000; Engler, 2009).

1.2.2 Neuroticism

The etymology of neuroticism is nerves and it means weakness of nerves in the Greek language (S. B. Eysenck & Eysenck, 1978). Neuroticism is a type of personality trait that refers to a constant inclination towards negative emotions and higher levels of anxiety (H. J. Eysenck & Eysenck, 1986; S. B. Eysenck & Eysenck, 1978). It is broadly assumed to be a risk factor for psychiatric disorders (S. B. Eysenck & Eysenck, 1978; Lahey, 2009; Osorio, Cohen, Escobar, Salkowski-Bartlett, & Compton, 2003; Watson & Clark, 1984). Emotionally strong reactions together with lower adjustment skills cause high neurotics to behave unreasonably (H.J. Eysenck and Eysenck, 1975). If neurotic individuals have to be defined with a word, it would be “worrier”, someone who feels permanent apprehension and fears that something might go wrong, which leads to extremely anxious reactions to these thoughts (Eid & Diener, 1999; H. J. Eysenck & Eysenck, 1975; Flehmig et al., 2010).

Among the personality traits neuroticism has the strongest biological basis because it has been suggested that neuroticism is a psychological trait of profound public health significance (Trull & Widiger, 2013). One potential reason for that might be neuroticism associates with emotional instability (S. B. Eysenck & Eysenck, 1978). In detail, neuroticism is described by being emotional instability therefore while neurotics can behave optimistically, social, or happy (i.e. when there is no stressors) whereas in some cases they may act quite responsive, anxious due to higher level of arousal (H. J. Eysenck & Eysenck, 1986). It is believed that because of this emotional instability high level of neuroticism is the main precipitation factor of many mental and physical disorders such as anxiety, depression, bipolar etc (H. J. Eysenck & Eysenck, 1986). Moreover, well known personality related theories (i.e. arousal based theory, attentional control theory, dual mechanism of control) have proposed considerable cognitive impairments during processing of various emotional and working memory tasks in high neurotics rather than in extravert and psychotic people (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). Indeed, empirical studies has confirmed that high level neuroticism leads significant cognitive impairments in various cognitive tasks (i.e. working memory tasks, dual tasks) in compared to other personality traits such as extraversion, psychoticism (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). Therefore, apparently, neuroticism is a predictor of the quality of our lives (Trull & Widiger, 2013). Achieving a full understanding of the mechanisms through which neuroticism is linked to cognitive impairments, should be a top priority for research (Trull & Widiger, 2013). Knowing why neuroticism leads cognitive impairments should lead to improved understanding of commonalities among people (Trull & Widiger, 2013). It should be noted that, I do not intend to mean that other personality traits such as extraversion or psychoticism do not deserve investigation. I mean, in terms of cognitive tasks processing these personality traits (i.e. extraversion and psychoticism) have not been associated with a considerable cognitive impairment and they are not stronger predictor of varied psychological disorders as neuroticism. One potential reason for taht, in contrast to neuroticism, these traits somehow associates with stable pattern of characters (H. J. Eysenck, 1967; Szymura & Nęcka, 1998). For example, when neuroticism is not involved, extraversion is manifested by being social, talkative, and energetic (H. J. Eysenck & Eysenck, 1986). Similarly, when neuroticism is not involved, Psychoticism is manifested by being anti-social behaviors and risk taking (H. J. Eysenck & Eysenck, 1986). These patterns of features in extraversion and psychoticism rather stable (H. J. Eysenck & Eysenck, 1986). In other words, these patterns of characters dominantly observed in people with high level extraversion or psychoticism (H. J. Eysenck & Eysenck, 1986). Therefore, because of stability in other personality traits, arousal level may act normal and do not has a considerable impact on their cognitive mechanism (H. J. Eysenck, 1967; Szymura & Nęcka, 1998). Finally, as neuroticism has high prevalence and impact on our society, I preferred to investigate neuroticism rather than other personality traits.

In earlier studies, it was often assumed that highly extrovert participants were low neurotics because of a strong negative correlation between neuroticism and extraversion (H. J. Eysenck, 1967; Szymura & Nęcka, 1998). However, recent studies with larger samples have shown that a considerable portion of participants show high extraversion as well as high neuroticism, indicating that high extraversion is not identical to low level neuroticism (Bianchi & Laurent, 2016). Therefore, to investigate high and low neuroticism, recent studies prefer to select participants from top and bottom quartiles in the neuroticism scale (Bianchi & Laurent, 2016).

1.2.3 Relationship between Neuroticism trait and Anxiety trait

Anxiety is the major descriptor of neuroticism (H. J. Eysenck, 1967; S. B. Eysenck & Eysenck, 1978; Jorm, 1989). While neuroticism is the most commonly used term, other terms have been used in the literature to describe the same or very closely related personality traits, such as trait anxiety, negative affectivity, or emotional arousability (Jorm, 1989). Because some researchers have proposed their own theories and classified personality traits in different ways, traits identical or similar to neuroticism are differently named (Jorm, 1989). For example, according to H. J. Eysenck & Eysenck, (1986) neuroticism is similar to trait anxiety. Cattel (1969) used term trait anxiety instead of neuroticism in his personality theory. Therefore, different terms are usually related to different measurements (Jorm, 1989). For example, the differences between the Eysenck Personality Questionnaire (EPQ) (H. J. Eysenck & Eysenck, 1975) and the State and Trait Anxiety Inventory (STAI) (Spielberger, 1983) is that while the EPQ assesses several personality traits (i.e. neuroticism, extraversion, introversion and psychotics) (H. J. Eysenck & Eysenck, 1975), the STAI is specifically focused on trait anxiety and current anxiety level (Spielberger, 1983). In this context neuroticism seems to be equivalent to trait anxiety because both terms refer to an inclination towards negative affectivity and anxiety (Jorm, 1989). The correlation between these trait measurements varies from .71 to .81 (Jorm, 1989). Therefore, trait anxiety and neuroticism are assumed to be tapping similar personality traits (Fahrenberg, 1992; Gray, Braver, & Raichle, 2002; Jorm, 1989).

Furthermore, the detrimental effect of both neuroticism (H. J. Eysenck, 1967) and trait anxiety (M. W. Eysenck, Derakshan, Santos, & Calvo, 2007) is taken to be a manifestation of worry and arousal during the processing of tasks. Thus, while there may be some conceptual differences between the personality traits of neuroticism and trait anxiety, interestingly they have both been described as negatively affecting cognitive performance (H. J. Eysenck, 1967; Studer-Luethi et al., 2012). Importantly, for neuroticism and trait anxiety it has been proposed that the mechanisms of how and why performance is negatively affected are virtually identical, i.e. it is a consequence of worrying and arousal during the processing of tasks (Bishop, 2007; Studer-Luethi et al., 2012). Consequently, theories of how neuroticism affects cognitive performance and how trait anxiety affects cognitive performance are very similar and have frequently been used interchangeably, i.e. applied to the respective other domain (e.g. neuroticism-based studies have used trait-anxiety theories to explain their findings,) (Bishop, 2007; M. W. Eysenck et al., 2007; Gray et al., 2002; Studer-Luethi et al., 2012).

1.2.4 Neuroticism in Personality Models

In the field of psychological research two distinctive personality models are broadly applied: Eysenck Personality Giant Three (H. J. Eysenck & Eysenck, 1975) and Big Five (Costa & McCrae, 1985). While the two models differ in terms of the numbers of personality traits, importantly for the current project, they agree that neuroticism is one trait, and they also conceptualise it in a very similar way. In more detail, according to H. J. Eysenck & Eysenck, (1975) there are three traits: extraversion, neuroticism and psychoticism. On the other hand, the Five Factor Model, known as the Big Five (Costa & McCrae, 1985), includes five traits: Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness to Experience. These two models use the same term, neuroticism, to describe a constant inclination towards negative affectivity. However, to measure their personality traits H. J. Eysenck & Eysenck, (1975) use the Eysenck Personality Questionnaire (EPQ) and Costa and McCrae, (1985) use the Five Factor Inventory (FFI). In both measures, term neuroticism shares many common aspects with each other and they are highly correlated (r= 0.7–0.9) and reliable (P<0.01) (Zawadzki, Strelau, Szczepaniak, & Śliwińska, 1998). However, the EPQ has been tested in 34 countries and the neuroticism traits are found to be highly correlated in terms of reliability and validity in all countries (Francis, Brown, & Philipchalk, 1992; Saggino & Lauriola, 1999). In particular, the reliability and consistency of the EPQ has been replicated in many countries including Turkey (Karanci, Dirik, & Yorulmaz, 2007) and the UK (H. J. Eysenck & Eysenck, 1975; S. B. Eysenck, Eysenck, & Barrett, 1985). Therefore, I prefer to use the EPQ in this study because my study samples are from an international university (UK: Brunel University London) and a national university (Turkey: Dicle University, Diyarbakir).

1.2.5 Summary of Personality and Neuroticism

Neuroticism is described as an inclination towards negative affectivity and other psychological disorders (H. J. Eysenck & Eysenck, 1986). Traits similar or identical to neuroticism are named differently in other personality measurements such as trait anxiety (Jorm, 1989). Generally, the detrimental effects of these terms (i.e. neuroticism, trait anxiety or negative affectivity) are used as a manifestation of arousal and worry during cognitive task processing (H. J. Eysenck, 1967; M. W. Eysenck et al., 2007). It has been suggested that cognitive processing, particularly in working memory performance (i.e. dual tasks), is negatively influenced by high levels of neuroticism (Corr, 2003). I aim to investigate the effect of neuroticism on working memory (WM) and dual tasks and therefore, before describing theories that describe this relationship in detail, I need to introduce the concept of WM in a general sense. Therefore, below, in the section 1.3., I discuss working memory in order to provide a better understanding of the theories and studies of neuroticism in relation to cognitive processing.

1.3 Understanding Working Memory

In this section the concept of working memory is provided. I will present working memory (WM) here in order to aid a better understanding of neuroticism related cognitive theories and empirical studies which are investigated neuroticism related differences during processing of WM tasks because these investigations generally based on the WM model of A. D. Baddeley & Hitch, (1974). Later, I discuss the main components of working memory that are strongly associated with the current study through recent related theories.

Working memory (WM) refers to a mechanism for temporarily maintaining and manipulating information. The idea of cognitive processing of temporarily stored information is based on the concept of short term memory (originally called primary memory), which is only about maintenance. This was then extended to also include the processes needed for the manipulation of information to make it WM (Baddeley, 1997; Baddeley, 1986; Engle, 2002; Miyake & Shah, 1999).

One of the first WM models was proposed by Baddeley & Hitch in 1974. Their model includes two basic short term stores (the phonological loop and visuospatial sketchpad), an episodic buffer and a central executive system. In this model, the short term systems are complemented by a control system, the central executive system (CES), which controls, regulates, manipulates and integrates information. Such functionality is usually required in complex cognitive tasks such as multitasking.

1.3.1 Phonological loop (PL), visuospatial sketchpad (VSSP) and episodic buffer

As indicated above, two components of short term memory are supervised by the central executive system but these storages (the phonological loop and visuospatial sketchpad) have their own independent repositories. The phonological loop consists of two components (the phonological store and an articulatory rehearsal processes), and it deals with auditory and verbal information. The visuospatial sketchpad, which also consists of two components (the visual cache and inner subscribe) is involved in encoding, storing and retrieving visuospatial information (Baddeley & Hitch, 1974; Baddeley, 1997; Baddeley, 1986).

The phonological store is associated with the mind's ear, meaning when one reads verbal information they hear it in their mind, whereas the articulatory rehearsal process is associated with the mind's voice, which means when one repeats the information internally (Baddeley, 1997; Baddeley, Allen, & Hitch, 2011; Baddeley, 1986). For example, when a verbal stimulus is presented, it will be acoustically/phonologically encoded, which refers to echoic memory (Baddeley, 1997). The information is converted into sounds and maintained in an echo-box in the phonological store (Baddeley, 1997; Baddeley, 1996b). Therefore, if not refreshed, the information decays in approx. 2 seconds (Baddeley, 1997; Baddeley, 1986). Thus, to avoid losing information, the articulatory rehearsal becomes active to refresh information by rehearsing it via the internal voice (Baddeley, 1997; Baddeley, 1996b; Gathercole & Baddeley, 1990). When the rehearsal process is completed then the information maintains in the phonological loop and this process is repeated until the memory task is completed (Baddeley, 1997; Baddeley, 1986; Baddeley, 1996b).

Visuospatial sketchpad storage is associated with encoding and temporarily storing visual and spatial information. Therefore, it consists of two processes, which are visual and spatial processes. In other words, this storage deals with the encoding of what and where information. The visual process involves encoding and storing an object's colour, shape etc. The spatial process involves encoding and storing the location of stimuli. Similar to the phonological loop, visuospatial sketchpad storage has been divided into two components, which are the visual cache and inner scribe. The visual cache is a relatively passive component that deals with storing visual information. The inner scribe is a dynamic component that deals with the retrieval and rehearsal of information. For example, when a visuospatial stimulus is presented, it is maintained in the visual cache. If not refreshed by the inner scribe, the information decays in a few seconds. After storing information in the visual cache, visuospatial information is retrieved by the inner scribe (Baddeley, 1986; Baddeley, 2007; Baddeley, 2012).

The episodic buffer is a relatively new component of working memory, which has an assistive role for storage systems. It is assumed to bind together information from PL and VSSP to provide a coherent percept. (e.g. one has a representation of the visual and auditory information about a person). Therefore, it manages to combine information that includes auditory, verbal, and spatial information in the working memory. Also, it is supposed to be storage for complicated information, i.e. prolonged episodes or events (Baddeley et al., 2011; Baddeley, 2000; Baddeley, 2007; Baddeley, 2012).

A very important further component of WM is the central executive system. Because this is central to this study, I will assess it in a separate subsection.

1.3.2 Central executive system (CES)

The central executive system (CES) plays a supervisory role in the short term memory components (Baddeley, 1996b; Baddeley, 2007; Baddeley, 2012). This control system manages the dismissal and elimination of information in the store of short term components (Baddeley et al., 2011; Baddeley, 1996a; Baddeley, 2012). CES is as a supervisory controller favours the storage systems to work efficiently in workspaces of mental processes (Baddeley, 2012). Furthermore, it assigns which component of short term memory - either the phonological loop or visuospatial sketchpad - is recruited for information (Baddeley, 1986; Baddeley, 1996a; Della Sala, Baddeley, Papagno, & Spinnler, 1995). It manages the integration and cooperation of the other components, the episodic buffer, phonological loop, and visuospatial sketchpad (Baddeley, 1996a; Della Sala et al., 1995). Finally, it allocates cognitive resources to deal with the integration, regulation, manipulation, transformation, and suppression of mental representations (Baddeley et al., 2011; Baddeley, 1986). Because the CES is at the centre of WM, it is involved in many cognitive functions (Baddeley, 1986; Shipstead, Redick, & Engle, 2012; Shipstead, Harrison, & Engle, 2015). Although the location of the CES is supposed to be divisible in the brain, the frontal lobe areas seem to be strongly associated with this system (D'Esposito et al., 1995; D'Esposito & Postle, 2002; Jonides et al., 1993). Even on such a very coarse and unspecific anatomical level, the consensus is that the CES functions are sub-served by a fronto-parietal network (Della Sala et al., 1995; D'Esposito et al., 1995; D'Esposito & Postle, 2002; Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008; Ruthruff, Miller, & Lachmann, 1995; Salmon et al., 1996).

The current concept of CES relies on two proposals (Baddeley, 1997; Baddeley, 1998; Baddeley, 2012; Salmon et al., 1996). The first proposal is that the CES acts as an attentional controller and the second proposal is that the CES has limited attention (Baddeley, 1998; Baddeley, 2012; Salmon et al., 1996). Therefore, when investigating the CES in relation to cognitive task processing, an ideal task could involve higher attention as well as concurrent performance for divided attention (Baddeley, 1998; Salmon et al., 1996). In this context, dual task processing requires extensive use of CES and thus it is one of the distinctive ways of investigating the role of executive functions in a direct way (Baddeley 1996, 1998). In these types of dual tasks, research usually combines two memory tests (i.e. a visuospatial tasks and auditory tasks) and participants are required to perform these tasks concurrently (Baddeley, 1996a; Salmon et al., 1996). Therefore, dual task experiments are widely used to explore the role of CES based on the main assumption that performing two tasks concurrently places a demand on the CES (Baddeley, 1996a; Baddeley, 1998). For example, in a dual task study conducted by Baddeley (1996), one task was a random generation task that was supposed to disturb the operation of the CES. In the task the participants were required to generate sequences of letters and they were instructed to generate those letters in as a random order as possible. The second task was a Wisconsin card sorting test (WCST). In this test, there are two ways of sorting the cards, either based on colours or numbers. Initially they were instructed to sort the cards based on the colours. Following that the experimenter changed the card sorting criteria and they were instructed to sort the cards based on their numbers. The participants performed these two tasks separately as single tasks. Under dual task conditions, both tasks were combined and thus the participants were required to perform dual tasks in rapid succession. As a result, when the participants performed these tasks concurrently the task processing was significantly impaired. Because both tasks (RNG and WCST) (each individually by itself) demand the CES, the amount of impairment was greater for the dual task. In another experiment, a dual task was studied that consisted of a memory span task and an RNG (Baddeley, 1996a). The task demands were manipulated either by increasing the load on the memory span or by reducing the time limit for responses in the RNG task. The first task was an RNG task (demand on the CES) involving key pressing. In this task, the participants were required to produce numbers in an order in a certain time (0.5, 1 or 2 sec.). The task demands were increased as a sequence of numbers had to be generated from in 2 sec. and then 0.5 sec. The second task was a memory span task. In this task, the participants were required to recall sequences ranging from one item to eight items (demands PL). Baddeley (1996) found that increasing task demand in memory span tasks does not influence RNG processing. However, increasing the demand on RNG influenced task processing negatively in both tasks. This result indicates that task demand in the CES causes a considerable impairment during task processing whereas when demand increases in storage systems, the CES remains relatively unaffected (Baddeley, 1996a).

According to Baddeley, the CES does not need to be a totally unitary system; it can be divisible into functions to some degree, such as switching, inhibition, updating, planning etc. (Baddeley, 1998; Baddeley, 2012). Switching refers to shifting from one task to another (Baddeley, 1996a; Monsell, 2003). Inhibition refers to avoiding other distractors and keeping the focus of attention on the required target (Friedman & Miyake, 2004; Miyake et al., 2000). Updating refers to temporarily maintaining the task related context and instructions until the task has been executed (Miyake et al., 2000). Planning refers to the evaluation and selection of a sequence of task related information (Shallice, 1982). According to Baddeley (1996) task demand can be increased specifically on one of the CES functions. For example, he explored the role of the switching function of the CES, which is differentiated from general WM demand (Baddeley, 1996a). In the first task (RNG) the participants were asked to press keys in one second. In the second task the participants were either required to recite the letters from alphabet only each second or alternate between letters and numbers. Thus, in one dual task condition, the participants performed RNG for the first task and recited the alphabet in the second task. In another dual task condition, the participants performed RNG as the first task and alternated between letters or numbers. As a result, when the dual task consisted of RNG and reciting the alphabet, random generation by key pressing was not affected. Because RNG demands CES and the task of reciting the alphabet does not, task processing in RNG remains relatively unaffected. However, when the dual task consisted of RNG by key pressing with an alternating task, the randomness in the RNG was considerably reduced, because in this study both tasks demand the CES (RNG and the alternating task). Specifically, the alternating task places extra demand on the switching function. Higher interference occurred in the processing of the both tasks (dual task with higher switching demand) compared to the previous dual task condition (dual task with lower switching demand).

A dual task combining two memory tasks has also been widely applied to compare two groups such as high and low neurotics (Corr, 2003; M. W. Eysenck, Payne, & Derakshan, 2005; Szymura & Wodniecka, 2003). Because neuroticism is supposed to have a detrimental effect mainly on CES, high neurotics usually show higher task impairment compared to low neurotics, and this is evident either in their longer response times (Corr, 2003) or higher error rates (Szymura & Wodniecka, 2003). In particular, if one of the tasks involve the central executive system (i.e. dual task: Corsi block and WCST) in dual task performance, high neurotics show higher task impairment compared with when the dual task consists of two tasks that are associated with slave systems (i.e. dual task: corsi block and articulatory suppression) during dual task processing (M. W. Eysenck et al., 2005).

Another impressive study about the function of CES was conducted by Miyake et al. (2000). It relied on Baddeley's (1974) WM model. He used latent variable analysis to determine the main functions of the central executive system. He selected several standard WM tasks that have been proposed for investigating central executive functions by various researchers (Baddeley, 1996a; Smith & Jonides, 1999). 137 participants performed several tasks including the Wisconsin Card Sorting Test (WCST), and the Tower of Hanoi (TOH). He suggested that three main functions of the CES correlate with each other but obviously, they can be divisible. These are the shifting, inhibition and updating functions of CES. As briefly mentioned above the switching function is one of main control processes in the CES. It fulfils the function of shifting attention between tasks, and scheduling sub-tasks to execute related instructions. The switching function plays a pivotal role in dual task coordination and WCST task processing (Miyake et al., 2000; Monsell, 2003). Inhibition is described as the ability to avoid an automatic or dominant response to respond to necessary stimuli. Thus, it can be imagined as an attentional controller to prevent disruption or interference from task irrelevant activities and keep the focus of attention on task relevant activities (Friedman & Miyake, 2004; Miyake et al., 2000). It has been suggested that the inhibition function actively works during WCST and TOH processing (Miyake et al., 2000). Finally, the updating function fulfils maintenance of task related context, instructions and coding representations during task processing (Miyake et al., 2000). It has been suggested that the updating function is also involved in storage systems (Friedman & Miyake, 2004; Miyake et al., 2000). The updating function may be activated in dual tasks to maintain a number of stimuli and the task related context (Miyake et al., 2000). For instance, in a spatial working memory task (SWM) the location of a number of items needs to be maintained (M. W. Eysenck et al., 2007; Miyake et al., 2000). Similar to the study by Miyake et al., (2000), I have selected similar tests from the Cambridge Neuropsychological Test Automated Battery (CANTAB) (i.e. WCST is similar to IED set shifting; SOC is similar to TOH). In this way, I aim to test the detrimental effect of neuroticism in relation to the CES functions. I have also included a SWM task identical to the Corsi block because I want to test the effect of neuroticism in relation to visuospatial storage as well.

The relationship between neuroticism and the performance of these types of dual tasks will be elaborated in more detail below in section 1.5. In what follows, I will discuss the CES functions more generally and describe the paradigm I used to investigate the effects of neuroticism on the CES functions, namely the paradigm of the psychological refractory period (PRP).

1.3.3 Executive functions in Dual-task PRP paradigms

The research described in the last section used dual-tasks mainly to delineate which potential components of the Baddeley model (1974) are demanded by different tasks, and whether certain components are independent of each other. While these tasks are perfectly suited to those purposes, they are not ideal for the current study. In the current study, in which I aim to understand the effect of neuroticism on the CES demands in dual-task performance, i.e. multitasking, it would be beneficial to use an experimental design that allows for perfect control of the temporal concurrency of the tasks. One paradigm fulfilling this purpose is the psychological refractory period (PRP paradigm). Therefore, I will use this paradigm in most of my study.

In PRP dual task procedures, the concurrent performance of two tasks (R1 and R2) which are required two stimuli (S1 and S2) that are presented in a rapid succession with an interval between two tasks (stimulus onset asynchrony [SOA]) (see figure 1.1.) (Logan & Gordon, 2001; Meyer & Kieras, 1997a; Pashler, 1993; Schubert & Szameitat, 2003). The general finding is that the response to the second stimulus is prolonged in dual task processing as compared to single task processing. This prolongation depends on the duration of SOA, which is the so-called PRP effect (De Jong, 1995b; Logan & Gordon, 2001; Telford, 1931). Thus if SOA is short a higher PRP effect is observed (Logan & Gordon, 2001; Meyer & Kieras, 1997a; Pashler, 1993).

The reason for the delay in the processing of the second task is explained by one of the most prominent PRP theory, called the response selection bottleneck (RSB) theory. According to the RSB-theory, the processing of a task requires three main stages, which are perception, response selection and motor execution (Logan & Gordon, 2001; Ruthruff et al., 1995; Salvucci & Taatgen, 2008; Tombu & Jolicœur, 2005). The perception stage involves perception and external analysis of the stimulus, whereas the response selection stage is associated with decision processes about the requirements of the task and the execution of a proper reaction (Logan & Gordon, 2001; Ruthruff et al., 1995; Salvucci & Taatgen, 2008; Tombu & Jolicœur, 2005). Finally, the motor response stage involves the fulfilment of the actual response (e.g. responding by finger pressing) (Logan & Gordon, 2001; Ruthruff et al., 1995; Salvucci & Taatgen, 2008; Tombu & Jolicœur, 2005). According to this model, the response selection stage has firmly serial procedure and this is the reason why a bottleneck is constituted when two tasks are processed simultaneously. It has been suggested that the response selection stage can process only one task at a time and, thus, this constitutes a bottleneck within the processing of dual tasks (Logan & Gordon, 2001; Ruthruff et al., 1995; Salvucci & Taatgen, 2008; Tombu & Jolicœur, 2005). Because the response-selection processing of the second task has to wait until the response-selection processing of the first task has finished, the response time for the second task is prolonged (see figure 1.1.) (Logan & Gordon, 2001; Marois & Ivanoff, 2005; Schubert & Szameitat, 2003). In other words, in PRP dual-tasks with short SOAs, the two tasks interfere with each other at the stage of the bottleneck, because they compete in terms of processing (De Jong, 1993; Marois & Ivanoff, 2005; McCann & Johnston, 1992; Pashler, 1989; Pashler & Johnston, 1989; Schubert & Szameitat, 2003; Schumacher et al., 1999). It has been shown that the CES is involved in managing the information streams of the two tasks and in resolving the interference between them (De Jong, 1995b; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997b).

In PRP dual tasks, the PRP effect, response times and error rates for each task can be analysed separately. This allows for determining where the impairment occurs in dual task processing (Pashler, 1994b; Schubert, 2008; Szameitat et al., 2011). Therefore, by comparing high and low neurotics in dual task processing, I will able to determine whether impairment occurs in the bottleneck, by looking at the response times and error rates in the dual task costs.

A further advantage of the PRP paradigm for the current study is that performing a PRP dual task demands the CES (i.e., one can create a complex CES-demanding task by combining two very basic (probably) non-CES-demanding tasks) (De Jong, 1995b; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997; Szameitat et al., 2016). By using this paradigm, task processing in a single task that is basically very simple and does not require a significant executive function and a dual task that requires extensive use of executive functions can be compared (De Jong, 1995b; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997b; Szameitat, Vanloo, & Müller, 2016). This comparison allows for exploring the CES and non-CES tasks. In particular, it has been suggested that the inhibition, switching and updating functions of the central executive system might play a pivotal role during processing in the bottleneck stage (De Jong, 1995a; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997; Szameitat et al., 2016). Accordingly, inhibition is assumed to be used to avoid processing the second task until the first task is processed in the bottleneck and switching is supposed to be used to shift the focus of the bottleneck from the first task to the second task. Also, updating may be used to maintain the first and second task related context and rules until both tasks are processed (De Jong, 1995a; Logan & Gordon, 2001). This assumption is worthy of consideration because these main functions of the central executive system proposed by Miyake et al. (2000) fit well with the overall explanation of the executive functions in PRP dual tasks (Szameitat et al., 2016). The notion that PRP tasks demand the CES is further supported by imaging studies, which have shown that PRP tasks also activate the fronto-parietal network sub-serving executive functions (De Jong, 1995b; Dux, Ivanoff, Asplund, & Marois, 2006; Schubert & Szameitat, 2003; Szameitat et al., 2016). Thus, the WM related brain activations and PRP dual task related activations are located in the same regions (Schubert & Szameitat, 2003).

Therefore, I took the PRP paradigm as a measure of the central executive functions (De Jong, 1995b; Luria & Meiran, 2003; Sigman & Dehaene, 2005; Szameitat et al., 2016). The high experimental control and elaborate theories (e.g. RSB-theory (Pashler, 1984), executive-process interactive control (EPIC: Mayer and Krieas, 1997), Executive Control of Visual Attention (ECTVA: (Logan & Gordon, 2001)) allow for understanding more exactly where in their mental processing the problems of high neurotics are located. Therefore, the paradigm is extremely well controlled and understood and thus it may allow for a detailed understanding of possible impairments caused by neuroticism.

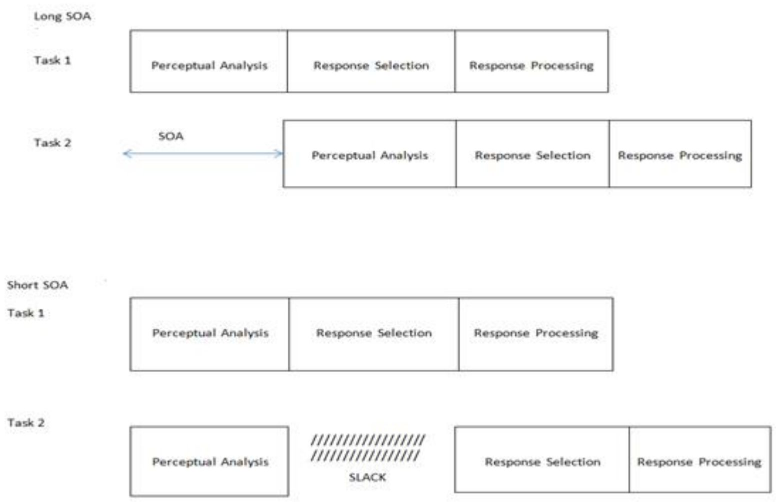

Figure 1-1 shows processing of two tasks in long and short SOA manipulations. RSB-Model is for the psychological refractory period.

To understand better the role of these functions regarding dual tasks, I should point out a distinctive factor called preparation processes (Szameitat et al., 2016). Preparation processes require mental processes just before task execution (Szameitat et al., 2016). PRP dual task studies suggest that preparation requires the switching function of the central executive system to switch the bottleneck to the first anticipated task (De Jong, 1995b; Luria & Meiran, 2003; Szameitat et al., 2016). Thus, better preparation requires a better switching function and this leads to reduced dual task cost during task performance (De Jong, 1995b; Luria & Meiran, 2003; Szameitat et al., 2016). Also, the inhibition function needs to be used to avoid second task processing until the first task is processed (Logan & Gordon, 2001). Note that, it has been suggested that preparatory processes are more likely to be associated with choice response tasks because they have a higher load to be prepared and a higher chance of an increased preparation process due to the multiple choices (De Jong, 1995b; Szameitat et al., 2016).

There are few remarkable behavioural studies (De Jong, 1995b; Luria & Meiran, 2003) that investigate the PRP paradigm in relation to CES. The experimental design and findings of these studies are helpful to understand the role of the executive functions in PRP dual tasks. These behavioural studies found that PRP dual task processing involves the switching, inhibition and updating functions (De Jong, 1995b; Luria & Meiran, 2003). For example, in dual task processing, the second task, which is the interrupted task, has to be avoided by inhibition function until the first task is processed, and then the processed task should be shifted to interrupted tasks via the switching function (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). Moreover, all of these tasks related schedules and contexts need to be monitored by the updating function (De Jong, 1995b; Luria & Meiran, 2003). For example, De Jong (1995b) conducted a series of dual task experiments with fixed and random task orders that required the extensive use of the executive functions. In fixed order tasks, the task orders were always either visual and then auditory (V-A) or auditory and then visual (A-V). Thus, the fixed order task was V-A, V-A, V-A, V-A… or A-V, A-V, A-V, A-V... However, in the random task, the task order was presented interchangeably, and thus the random task presentation was, for example, V-A, A-V, V-A, A-V, A-V, V, A… Participants were required to respond to randomly presented stimuli based on certain cues, and thus they could decide on their response sequence. He found that the dual task cost was considerably higher when the tasks order unpredictable and random. According to De Jong (1995b) one reason for higher dual task cost is the demand on the switching and inhibition functions. Because the task order was random, the task scheduling order needed to be rearranged each time. Thus, demand on the inhibition function was dominant because the interrupted task has to wait until the first task processed (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). The demand on the switching function was dominant as well because the focus of attention had to be switched from one task (which was processed in the bottleneck) to the other task (the interrupted task that needed to be reinstated) (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016).

Those findings were later investigated further using neuroimaging studies. For example, Szameitat et al., (2002) conducted a dual task including fixed and random conditions to investigate the central executive system. Participants were required to respond to fixed dual task modalities in a changeless order (i.e. A, V-A, V-A, V-A or A-V, A-V, A-V). On the other hand, similar to the study of De Jong (1995b) the task order was presented pseudo-randomly in the random dual task condition (e.g. V-A, A-V, V-A, A-V, A-V, V, A), which increased the role of the switching and inhibition function. Participants were required to perceive the order of presentation of the stimuli and then give the proper response. The dual task cost was found to be higher in fixed and random tasks compared to single tasks. Furthermore, the dual task cost was considerably greater in random dual tasks than in the fixed dual task conditions due to the higher demand on the central executive function without increasing the memory load. These results indicate that the load on the central executive functions places additional demand for each task in random conditions (Szameitat, Lepsien, von Cramon, Sterr, & Schubert, 2006; Szameitat et al., 2002). Thus, the processing of each task takes longer in the bottleneck because task related information and the subtask order need to be rearranged each time (which is heavily associated with switching and inhibition) and updated in the serial processing of the task order (Stelzel, Kraft, Brandt, & Schubert, 2008a; Szameitat et al., 2002). These findings of Szameitat et al., 2002 later confirmed by a further study of Szameitat and his colleagues in 2006. Szameitat Lepsien, von Cramon, Sterr and Schubert, (2006) investigated neural correlates of task order coordination in dual tasks. In this study participants performed three choices reaction tasks. They required to detect location of a square (right, left or middle) and respond accordingly in visual tasks whereas in auditory tasks they required to detect a tone whether it is high, low, or moderate Hz and respond accordingly. Participants performed dal tasks with fixed and random orders. The results showed that dual task order coordination associates with prefrontal lobe activations (i.e. IFG, MFG) and higher activations in the regions were observed as the demand on task order increase. These findings suggest that dual task order coordination requires a profound use of executive functions which associates with prefrontal regions.

Complementing the study of Szameitat, et al., (2002), which investigated task coordination, particularly associated with the switching, inhibiting and updating functions of central bottleneck, Stelzel, et al., (2008) explored the effect of task coordination and maintenance. The study consisted of random and fixed dual tasks with a manipulated set size from two to four choices stimuli-response (S-R) mappings. In the dual tasks, participants were required to respond to one of four digits presented in the centre of the screen by pressing either one of four (4-choice tasks) or two buttons (2-choice tasks) on the keyboard. Similarly, they had to respond to one of four auditory stimuli with different HZ frequencies by pressing one of four buttons (4-choice tasks) or two buttons (2-choice tasks) on the keyboard. Accordingly, it was found that the dual task cost was greater either with a higher set size or random task. However, the effect of dual cost for maintenance was associated with the premotor cortex bilaterally and the left anterior insular cortex, whereas the cost related to the random task involved the inferior frontal sulcus (IFS) and the middle frontal gyrus (MFG). These results indicate that the task demand, in particular on the switching and inhibition function of the central executive system and the demand, particularly on the maintenance function (or updating function of the central executive system) of working memory cause higher dual task costs. Thus they both influence the processing in the central bottleneck but they are associated with different regions of the brain.

Consequently, in dual tasks, the CES demand can be increased either by a random task (De Jong, 1995b; Luria & Meiran, 2003; Szameitat et al., 2002), which is called task coordination, or S-R mapping manipulation, which is called task set maintenance (Allain, Carbonnell, Burle, Hasbroucq, & Vidal, 2004; Stelzel et al., 2008a; Szmalec, Vandierendonck, & Kemps, 2005). When the S-R mapping is increased, the participants were required to make a choice among more choices than before (Szmalec et al., 2005). Because the response selection stage is a decisional process, when the response choices increase, this is associated with the response selection stage, which is the locus of the CES and bottleneck (Allain et al., 2004; Bunge, Klingberg, Jacobsen, & Gabrieli, 2000; Szmalec et al., 2005). Therefore, increasing demand by S-R mapping manipulation is associated with higher demand on the three CES functions (Szmalec et al., 2005) and this causes a higher dual task cost as in the random task (Stelzel et al., 2008a). However, the weight of the switching, inhibition and updating functions in S-R mapping manipulation changes as compared to random tasks with two choices. While the weight of switching and inhibition is higher in the random tasks (De Jong, 1995b), the weight of the updating function also seems to be higher in S-R mapping manipulation in dual tasks (Stelzel et al., 2008a). The reason for that is, the number of stimuli associated with the switching and inhibition functions are higher. Also, while in the random dual tasks there are always two S-R mappings involves in updating function, increasing S-R mapping manipulation in the dual task requires a higher number of choices and the task related context to be updated (Stelzel et al., 2008a). Taken together, performing dual tasks with either random task order or higher S-R mappings do increase demand on the three CES functions. While the weight of inhibition and switching is greater in random tasks, the weight of the updating function is relatively greater in S-R mapping manipulation.

Sigman and Dehane, (2005) elaborated characterization of bottleneck during processing of dual task. In the study while tone discrimination task (i.e. high and low tone) remain constant, visual tasks were number comparison tasks which are manipulated by using three different factors. These are notation task (the participants were required to decide whether the presented number is in Arabic or it is a spelled word), distance tasks (i.e. the participants were required to decide whether the number is larger or smaller than 45), and complexity task (the participants were required to either respond one time or two times in the task). The authors aimed to increase demand in each stage of dual task processing by these manipulations. It has been found that when the task demand is increased in perceptual or central stages (i.e. in the first task which is visual task) participants took longer time to process task 1 and task 2 in dual task performance whereas when the demand is increased in motor stage, this only leads longer RTs in the first task. According to the authors, bottleneck processing might be active and it involves in executive functions in the dual task processes. Moreover, these executive functions seem to be start to engage at starting point response selection just after perceptual stage in the first task processing. In other words, executive functions involve in dual tasks in between perception and bottleneck to schedule task orders and resolve interference. In line with these findings, Sigman and Dehane, (2006) investigated executive functions which involve in dual task processing by conducting a similar series of experiments. Participants performed dual tasks with various manipulations. It has been shown that participants become slower as SOA decrease. According to the authors the potential reason for that is the bottleneck involve in active processes and requires executive functions which schedule task orders (task setting) and resolve interference (task disengagement). It has been suggested while 'task setting' involves at the beginning of response selection stage to select appropriate task, 'task derangement' involve at the end of response selection stage to inhibit first task and switch the focus of attention on the second task (see figure 1-2). As it is indicated before task setting (updating, and switching) and task disengagement (switching and inhibition) strongly associates with three main function of central executive system. As results, this measure of behavioral costs reflects not only the PRP, i.e., the waiting of the second task for the first task to being processed, but also the executive functions which schedule the task processing at the bottleneck (De Jong, 1995; Luria and Meiran, 2003; Marois and Ivanoff, 2005; Sigman and Dehaene, 2005).

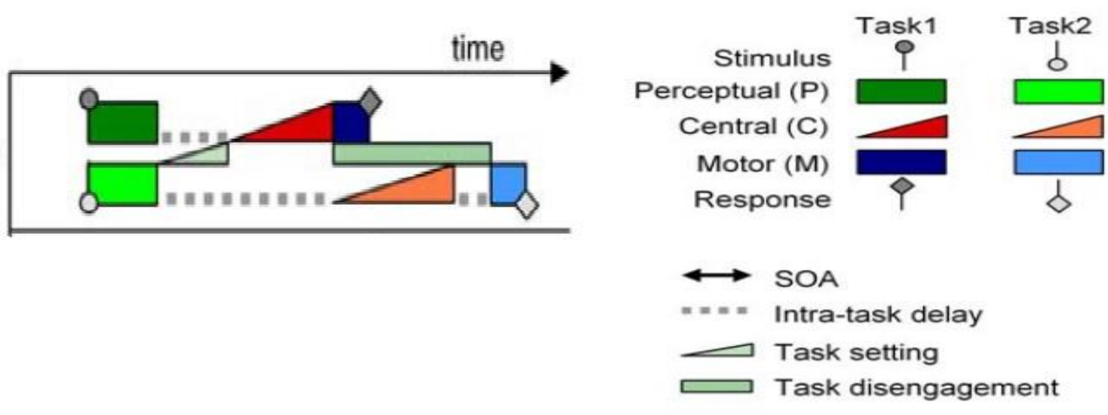

Figure 1-2 The model of Sigman and Dehane (2006) which supposes that a first central decision is required to select which task to perform first. They refer to this stage as task setting. A second postulate is task disangagement that

there is a temporary inhibition of the response to the second task, implying that it cannot be executed until the first task has been disengaged, as observed in task-switching paradigms (Sigman and Dehane, 2006).

So far, I have shown that the dual task PRP paradigm is supported by empirical and theoretical studies. It has been suggested that PRP dual task demand can be manipulated through the inhibition, switching and updating functions of the CES. Therefore, I used the PRP dual task paradigm in most of my studies to investigate the detrimental effect of neuroticism on the CES functions. Because in this section, I generally discussed behavioural evidence, in the next subsection, I will mainly discuss neuroimaging studies in relation to WM and PRP dual tasks.

1.3.4 Neuroimaging Evidence Regarding Working Memory and PRP Dual Tasks

In this section, three points related to neural correlates of WM are presented. First, I present findings of neuroimaging studies in standard WM tasks, PRP tasks, and other types of dual tasks. I present studies that give more detailed information about dual task related areas such as the Lateral Prefrontal Cortex (LPFC) (i.e. Inferior Frontal Gyrus (IFG), the inferior frontal junction (IFJ), the Middle Frontal Gyrus (MFG)) and the Anterior Cingulate Cortex (ACC). Secondly, I discuss specific working memory task demand (i.e. the demand on CES functions) and nonspecific demand on the tasks (i.e. task difficulty by degrading stimuli). Finally, I discuss the direction of neural activation in the brain during the task processing (i.e. lower or higher activation) by giving examples from related empirical studies.

A considerable number of magnetic resonance imaging (fMRI) investigations have shown that cognitive processing of WM tasks is associated with a greater blood-oxygen-level-dependent (BOLD) signal in PFC, particularly in the dorsolateral prefrontal cortex (DLPFC), the ventrolateral prefrontal cortex (VLPFC), the dorsal anterior cingulate cortex (ACC) and the parietal cortex (PAR) (for reviews, see (D'Esposito et al., 1995; D'Esposito & Postle, 2002; Wager & Smith, 2003). For instance, one of the early neuroimaging studies that demonstrated that PFC is engaged during the processing of spatial working memory tasks was conducted by Jonides, Koeppe, Awh, Minoshima, & Mintum (1993) on monkeys. More specifically, the right Brodmann's area 47 (inferior frontal gyrus) was activated in the PFC during task processing. Also, several researchers have suggested that the PFC may also be activated in humans during cognitive processing of working memory tasks. For example, various studies have conducted delayed response tasks to investigate the functional neuroanatomical correlates of mental spatial representations (Baker, Frith, Frackowiak, &

Dolan, 1996; Goldman-Rakic, 1996; Sweeney et al., 1996) as well as non-spatial (i.e., letters, words, faces, objects) information (Paulesu, Frith, & Frackowiak, 1993; Salmon et al., 1996; Smith, Jonides, & Koeppe, 1996). Furthermore, various studies have investigated demanding and complex tasks such as dual tasks and n-back tasks (Petrides, Alivisatos, Evans, & Meyer, 1993; Petrides, Alivisatos, Meyer, & Evans, 1993; Salmon et al., 1996; Smith et al., 1996). These studies have consistently demonstrated greater LPFC activity in working memory tasks in comparison to single tasks.

The DLPFC and ACC are significant structures in the prefrontal cortex. They are associated with the CES (Carter et al., 1998; Carter et al., 2000; Devinsky, Morrell, & Vogt, 1995) and are influenced by personality (Canli et al., 2001; Eisenberger et al., 2005). Several neuroimaging studies have found that the DLPFC and ACC are dissociable during task processing (Baker et al., 1996). DLPFC activity is associated with the maintenance and manipulation of information in the absence of ACC activity in working memory (Baker et al., 1996). ACC activity is stronger than DLPFC activity when a task is associated with divided attention or when dealing with a dominant response. For example, in a Stroop task, sometimes the word and the colour are congruent (i.e. blue printed in blue ink) and sometimes they are incongruent (i.e. blue printed in red ink). Participants are often slower when they read a word automatically during incongruent conditions, which leads to higher ACC activation (Baker et al., 1996). In line with this, MacDonald et al. (2000) found that the roles of the DLPFC and ACC in cognitive control are disassociated. In this study participants performed a Stroop task associated with the switching and inhibition functions (congruent vs incongruent). The results show that while the DLPFC (i.e. BA 9) is associated with representing and maintaining task demand on the CES, the ACC (BA; 24, 32) is associated with the monitoring of errors and overcoming proponent response or response conflict. In addition, Cabeza & Nyberg, (2000) found that the ACC was strongly activated when participants performed working memory tasks such as problem solving, or verbal/numeric and spatial tasks. More specifically, while the caudal ACC is strongly activated during demanding working memory tasks, it is not activated during simple tasks (Paus, Koski, Caramanos, & Westbury, 1998). Therefore, it is presumed that the caudal ACC is affected by working memory demand during cognitive control because it is one of the important components of the cognitive control mechanism in the frontal lobe. Thus, in normal subjects, increased demands in working memory lead to greater activity in the caudal ACC during the processing of working memory tasks (Botvinick, Braver, Barch, Carter, &

Cohen, 2001; Bush, Luu, & Posner, 2000; Carter et al., 1998; Carter et al., 2000; Miltner, Braun, & Coles, 1997; Posner & DiGirolamo, 1998).

Although research aims of other dual tasks (i.e. which are combination of two WM tasks) and PRP dual tasks (i.e. which focus on bottleneck) are different, they both have common findings about dual task related areas in terms of neuroimaging studies. Therefore, various researchers have conducted dual task paradigms to explore the role of WM components (i.e. CES and slave systems) (Della Sala et al., 1995; Norman & Bobrow, 1975) or dual task bottlenecks in relation to the CES (De Jong, 1995b; Dux et al., 2006; Luria & Meiran, 2003; Pashler, 1994b; Schubert & Szameitat, 2003; Stelzel et al., 2008a). The common findings in these studies are that the dual task related areas are mainly associated with greater neural activation in the lateral prefrontal cortex (LPFC; for task coordination: MFG, IFG, IFS; and maintenance: premotor cortex and left anterior insular cortex) during dual task processing (Dux et al., 2006; Erickson et al., 2005; Schubert & Szameitat, 2003; Stelzel et al., 2008a; Szameitat et al., 2002) and medial prefrontal cortex (medPFC; maintenance and error execution: ACC and medSFG) (Carter et al., 2000; MacDonald, Cohen, Stenger, & Carter, 2000).

The researchers investigated dual task related areas usually by subtracting single task activations from a dual task (Adcock, Constable, Gore, & Goldman-Rakic, 2000; Bunge et al., 2000; Szameitat et al., 2011). For example, Bunge, et al. (2000) tested 8 participants to investigate the neural basis of the CES. Participants were required to perform either a short term memory task including 5 words or a sentence read separately as a single task. Thus, in one single task (such as the reading phase), participants were required to read sentences and decide whether the statement was right or wrong. The other single task was a recalling phase; 5 sentences were presented and participants were required to recall the last word of each sentence. In the dual task condition, participants were required to read the sentence and make a decision (whether it was right or wrong) and then they were required to recall the last word of the sentences while in the scanner. They found greater LPFC activations (covered from the right MFG to left IFG and extended in the bilateral anterior cingulate) in the dual tasks than in the single tasks but there were no additional activations in the LPFC. In other words, the same regions were activated in both the single and dual tasks but the activations were greater in these regions during the dual task processing.

Furthermore, PRP dual task studies have repeatedly found activations in the IFG, MFG, IFS and IFJ in relation to the PRP effect. According to Szameitat et al., (2016) the MFG, IFG and IFJ are associated with central bottleneck processing during dual task performance. In more detail, they have suggested that while the IFG is associated with switching, the MFG is associated with the inhibition function of the central executive system. For example, Schubert & Szameitat, (2003) conducted a PRP dual task experiment with eleven participants to investigate the neural correlates of interference in overlapping dual tasks. Participants were asked to determine a target square from three squares presented to them. They were asked to identify a pitch tone, whether it was high, moderate or low. While participants were required to perform these tasks separately as single tasks, they performed both tasks under varied SOA conditions, 50, 125, and 200ms in the dual task. Thus, the participants were required to avoid the second task until the first task had been processed by the inhibition function and then to switch the focus of attention and reinstate the second task processing via the switching function (Schubert & Szameitat, 2003; Szameitat et al., 2016). These two functions are dominantly needed for temporal coordination of dual task performance (Schubert & Szameitat, 2003; Szameitat et al., 2016). Accordingly, (Schubert & Szameitat, 2003) they found that the main focus of dual task related activations is covered with the left inferior frontal junction (IFJ) (i.e. MFG (BA 9, 46), IFG (BA 6, 9, 46)). Further PRP dual task studies found that the left IFJ (i.e. BA 9) (Dux et al., 2006; Schubert & Szameitat, 2003), left IFG (i.e. BA 9, 44, 6), left IFS (i.e. BA 9, 44, 6), and right MFG (i.e. BA 9, 6) (Stelzel et al., 2008a; Szameitat et al., 2006) are associated with dual tasks. Accordingly, these results suggest that the switching and inhibition functions of the CES are linked to the LPFC, which mediates temporal coordination of two tasks during dual task processing.

The findings in relation to CES functions (switching and inhibition) and LPFC (IFG, MFG) have been confirmed in standard WM tasks as well such as the Wisconsin Card Sorting Test (WCST) (i.e. right MFG (BA, 46, 44), left MFG (46, 9); IFG (BA,44, 45, 46); right ACC (BA, 9, 32) (Goldberg et al., 1998), or the Go-/No Go paradigm (Konishi et al., 1999) (i.e. left IFG (BA, 44, 45); bilateral IFS (BA 44, 45); left ACC (BA, 32).

While the majority of studies identify the lateral and medial prefrontal cortex as being related to dual task performance (D'Esposito et al., 1995; Goldberg et al., 1998; Schubert & Szameitat, 2003), some studies have failed to show this kind of association (Adcock et al., 2000; Klingberg, 1998). For example, Adcock et al., (2000) conducted a dual task study to investigate executive functions, which involved two types of dual tasks. The first dual task consisted of an auditory verbal categorization task (NOUN) and a visuospatial task (SPACE). In the auditory task the participants listened to a list of nouns and were required to categorize the nouns (such as fruit or vehicle). In the visuospatial task, participants were presented with two rotated boxes and one target box above. They were asked to decide which box was identical to the target box. The second dual task consisted of the same auditory task and a face identification task as the visual task. In the visual task, participants were required to identify which rotated face was identical to the target face. The participants also performed each of these tasks separately as single tasks. The results failed to show neural activations for the executive function in the brain. One reason for this inconsistency among the findings might be because of the paradigm that was used (Szameitat et al., 2002; Szameitat et al., 2011). Previous investigations have usually employed rather complex paradigms (Szameitat et al., 2002). Thus, participants could not process their control strategies in these complex paradigms (Szameitat et al., 2002). Therefore, participants may process the task without task interference in these experiments (Szameitat et al., 2002).

One point that should be raised is the potential reasons for higher and lower neural activations in dual task related areas during task processing. There are two factors that may affect neural activation differently (Szameitat et al., 2016). These are crosstalk and preparation processes (Szameitat et al., 2016). The term crosstalk is known as output conflict and it occurs when a stimulus that shares common aspects with the second stimulus causes an informational interference in the processing of the second task (Navon & Miller, 1987). It has been suggested that if the crosstalk is higher during the processing of the tasks, it is required to be resolved by avoiding one of the two tasks (Szameitat et al., 2016). In this case, greater activation in dual task related regions can be expected in the LPFC as the crosstalk increases (Herath, Klingberg, Young, Amunts, & Roland, 2001; Szameitat et al., 2016). However, crosstalk is mainly linked to simple-response tasks (Szameitat et al., 2016), and therefore in a demanding multiple choice task, crosstalk would be rather a weak factor (Szameitat et al., 2016). On the other hand, preparation refers to mental processes for switching the tasks just before task execution (Szameitat et al., 2016). As explained in section (1.3.3) preparation processes considerably affect interference. If dual task interference is exacerbated by preparation processes, the participant requires more and better preparation to reduce the dual task cost. If one had a better preparation during dual task performance this leads lower dual task cost and higher dual task specific activations (De

Jong, 1995a; Szameitat et al., 2016). However, if one does not prepare well during a demanding dual task performance, this may cause higher dual task cost which accompanied with lower neural activations in dual task related areas (Szameitat et al., 2016).

Another issue is related to the disassociation between specific working memory task demand and nonspecific demand on the tasks. It has been suggested that demand in working memory is disassociated from task difficulty in the brain (i.e. degrading stimuli make a task difficult at the perceptual level but not at WM) (Barch et al., 1997). It is important to understand this differentiation because I aim to test the effect of neuroticism in relation to CES demand and task difficulty in my study sample. For example, Barch et al., (1997), conducted a neuroimaging study to explore the disassociation between demand in working memory and task difficulty that is created by stimuli degradation. It has been indicated that stimuli degradation makes the task difficult but this difficulty is not associated with WM task demand, because degradation makes the task difficult at the perceptual level. The results demonstrated that increased demands on working memory lead to impairments in processing of the tasks, which are accompanied by higher DLPFC activation (left MFG; left IFG (BA; 46, 9)). However, task difficulty by degrading stimuli was associated with higher activation in the ACC (e.g. BA; 8), and other regions of the frontal cortex. These results show a disassociation between task difficulty and WM demand.

In summary, the majority of the neuroimaging studies indicate that WM processing and dual task processing is associated with higher activations in the fronto-parietal regions such as the LPFC (DLPFC and VLPFC; IFG, MFG) and ACC.

1.3.5 Summary of working memory

Working memory (WM) is described as a mechanism for temporarily maintaining and manipulating information (Baddeley, 1986). It consists of storage systems and the CES (Baddeley, 1986). To explore WM in relation to cognitive task processing, there are several standard WM tests (i.e. WCST, Corsi Block, TOH) and dual task paradigms that can be designed for CES investigations (Miyake et al., 2000). Among the dual task paradigms, the PRP paradigm is one of the best ways to investigate CES regarding task processing. The reason for that is that it is generally very well investigated and understood empirically. It is very detailed and advanced mental models are available (e.g. RSB-theory, EPIC, ECTVA). Neuroimaging studies show that the fronto-parietal areas, particularly the LPFC, are associated with WM and PRP dual tasks. As a starting point, I used the standard WM tasks such as identical tasks with WCST, TOH and SWM to test the neuroticism effect on the CES and VSSP. Furthermore, I used the PRP dual task paradigm extensively with varied manipulations to test the effect of neuroticism on the CES functions.

1.4 Effects of neuroticism on working memory

So far, I have described the concepts of neuroticism and WM, and the PRP dual task paradigm in relation to CES. In this section, I have discussed a few theories in relation to neuroticism. First I started with a theory (Arousal based theory) that is directly linked to neuroticism. Next, I made an argument that this theory is not well explained. Furthermore, I indicated the advantage of theories about trait anxiety and their explicit link with neuroticism. Following that, I discussed trait anxiety theories in relation to neuroticism.

1.4.1 Arousal based theory in relation to neuroticism

Yerkes–Dodson (1908) suggested an interactional model of performance and arousal during task processing. While performance refers to the accomplishment of a given task regarding response times and error rates, arousal refers to being alert physically and mentally (Yerkes & Dodson, 1908). According to Yerkes & Dodson (1908), the relationship between performance and arousal can be described by an inverted U shape (Fig. 1.2). Accordingly, the central nervous system is positively influenced by a moderately increased physiological arousal level for ideal task performance (Yerkes & Dodson, 1908). On the other hand, if arousal levels either overly exceed or drop below the optimal threshold this leads to diminished performance during task processing (Yerkes & Dodson, 1908). Furthermore, this model distinguishes tasks as simple and difficult or complex tasks and thus the arousal level increases according to the task demand or complexity (Bruya, 2010; Sanders, 1983). A very difficult task may lead to a higher stress level and arousal that negatively influence higher cognitive control to coordinate, maintain and execute during the task processing (Bruya, 2010; Sanders, 1983).

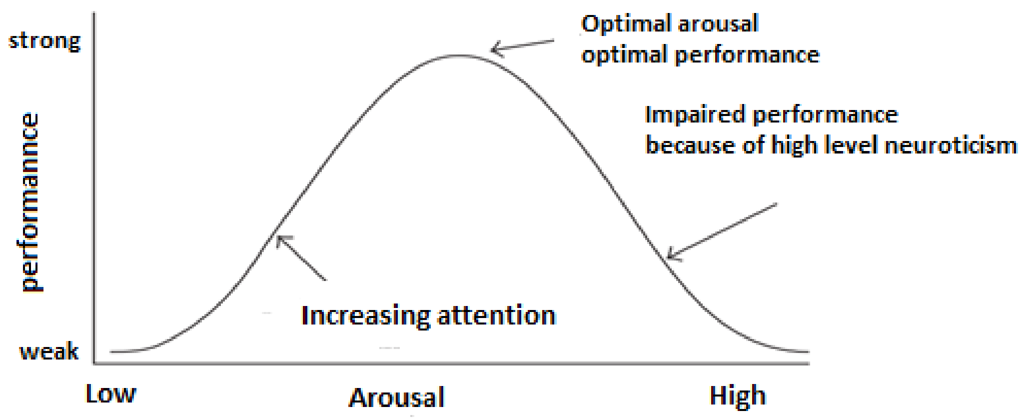

Figure 1-3 shows the relationship between performance and arousal as an inverted U shape curve

Based on this approach, Eysenck, (1967) assessed the physiological correlates of neuroticism regarding cognitive processing. He suggested that arousal and performance are linked by an inverted U-shaped function, i.e. performance is optimal at an intermediate level of arousal and deteriorates if arousal becomes too high or too low (Yerkes & Dodson, 1908). According to H. J. Eysenck (1967) and H. J. Eysenck & Eysenck, (1986), worry plays an important role in higher arousal level in high neurotics. Because high neurotics are 'worriers', they feel stressed easily, which may exacerbate a higher arousal level in difficult tasks (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Therefore, Eysenck (1967) suggests that high neuroticism results in a lower arousal activation threshold so that the inverted U-shaped function is skewed to the left, i.e. in the direction of lower arousal (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; Studer-Luethi et al., 2012). As a consequence, people with high levels of neuroticism have their optimal performance at lower arousal levels (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Translating this into the context of experimental tasks, it means that neuroticism has no effect on easy tasks, which result in low levels of arousal, because high and low neurotics do not differ in their relationship between arousal and performance (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; Studer-Luethi et al., 2012). However, for more demanding tasks, high neurotics show greater elevated levels of arousal, which limit their performance, while low neurotics may be at their best performance (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; Studer-Luethi et al., 2012). This proposal is supported by previous research showing an interaction between task difficulty (easy/hard) and neuroticism (low/high) such that the detrimental effects of neuroticism on cognitive performance are more pronounced for hard tasks (Corr, 2003; Poposki, Oswald, & Chen, 2009; Szymura & Wodniecka, 2003). One domain where this situation frequently occurs is multitasking, or dual-task performance. Here, the individual tasks are often easy, and so neuroticism has no major effect on their separate performance as single tasks (Pashler, 1994b). However, in a multitasking situation, i.e. when two or more tasks have to be performed at the same time, the tasks become much more demanding even if the single-tasks are very easy and basic (Corr, 2003; Pashler, 1994b). In line with this, previous research on multitasking has shown that high levels of neuroticism negatively affect multitasking performance more than single-task performance (Corr, 2003; Studer-Luethi et al., 2012).

According to Eysenck (1967), a higher arousal level in high neurotics causes greater cardiovascular activities than in low neurotics. This physiological difference can be observed by using either objective or subjective measures (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Higher cardiovascular activities cause high neurotics to perceive the task as more difficult than low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Therefore, after a difficult task is completed, if high neurotics score the task difficulty, they should report higher task difficulty than low neurotics (Poposki et al., 2009). In line with that, several empirical studies have used self-report measures in high and low neurotics (Poposki et al., 2009). The results show that high neurotics perceive higher stress than low neurotics in multitasking performance (Poposki et al., 2009).

Finally, it is known that the limbic system is associated with emotional processes (Canli et al., 2001). Because performing a difficult task causes higher arousal, which is a stressful situation for high neurotics, the arousal based theory of Eysenck (1967) suggests higher neural activations in the limbic system (i.e. amygdala) during difficult task performance in high neurotics. This assumption might be valid for emotional task processing, because in these tasks threatening emotional stimuli may cause higher stress (Canli et al., 2001). However, there is not much evidence in relation to cognitive processing that support this argument in high neurotics. The amygdala, and medial prefrontal cortex (PFC) are assumed to be neural correlates of high neuroticism during the processing of emotional information (Chan, Goodwin, & Harmer, 2007; Haas, Omura, Constable, & Canli, 2007). High neurotics often show increased amygdala activations during emotional processing of negative faces (Chan, Harmer, Goodwin, & Norbury, 2008). However, the majority of studies about cognitive task processing in high neurotics have reported LPFC activations during WM task processing (Bishop, 2007; Dima, Friston, Stephan, & Frangou, 2015). I will discuss the neuroimaging studies in relation to neuroticism in section 1.5.2.

1.4.2 Neuroticism in relation to arousal based theory and trait anxiety theories

This section is linked to section 1.2.4, where I discussed the relationship between neuroticism and trait anxiety. In that section, I concluded that despite the conceptual differences between neuroticism and trait anxiety they tap into similar personality traits. In this section, I discuss the limitations of arousal based theory in relation to Neuroticism. Following by that, I assess the advantages of trait anxiety theories because it would be suitable to utilize from these theories in relation to cognitive processing in high and low neurotics.

One concern that has been raised about Eysenck's theory (1967) (arousal based theory in relation to neuroticism) relates to the type of tasks. This theory only indicates that high neurotics have task impairment in difficult tasks, which leads to unanswered questions. For example, are high neurotics vulnerable to general task difficulty or is it specific to working memory? It is known that WM demand is differentiated from general task demand (Barch et al., 1997). If Eysenck (1967) (arousal based theory in relation to neuroticism) refers to general task demand, then one can assume that high neurotics will perform worse in any kind of demanding task that is not even associated with WM than low neurotics. This differentiation is not explicitly indicated in the theory; however, few empirical studies have assessed this theory in relation to WM task processing (Corr, 2003; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). In this context, if the term task difficulty refers to working memory demand then the question is, are WM components all equally influenced by neuroticism? Which component of working memory (Visuospatial storage, Phonological loop or CES) is influenced by the detrimental effect of neuroticism?

On the other hand, trait anxiety theories provide valuable assumptions regarding task processing in relation to trait anxiety. The relationship between the terms neuroticism and trait anxiety is assessed in section 1.2.3. For example, there are a few theories in relation to trait anxiety, which are presented below, such as processing efficiency (PET) (M. W. Eysenck & Calvo, 1992), attentional control theory (ACT) (M. W. Eysenck et al., 2007) and dual mechanism of control (DMC) (Braver, 2012). In the theoretical papers, several neuroticism studies refer to high neurotics as high trait anxiety subjects (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007; Gray et al., 2002). Because M.W. Eysenck (1979) suggested that it is reasonable to assume that high neurotic are high anxiety subjects, in the PET and ACT theories high neurotic individuals are assumed to be high trait anxiety subjects

(M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). Similarly, studies that have investigated cognitive processing in neurotics (using EPQ or FFI) have interpreted their results by relying on this trait anxiety theories (Flehmig et al., 2010; Robinson & Tamir, 2005; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). The empirical studies are also in line with this suggestion, as they have found that both high neuroticism and high trait anxiety are observed with similar behavioural and neural findings during WM task processing (Bishop, 2009; Dima et al., 2015). Therefore, I consider that it would be suitable to utilise trait anxiety theories in this thesis because of their detailed and comprehensive assumptions.

As a summary, the reason for using anxiety theories in neuroticism studies is that there are no neuroticism theories available that have the same level of elaboration.

1.4.3 Processing efficiency theory (PET)

Eysenck & Calvo (1992) proposed a processing efficiency theory to explain the association between neuroticism/trait anxiety and task performance based on Baddeley & Hitch's (1974) working memory model. Before discussing PET assumptions, as a reminder, it is necessary to briefly consider the concept of a working memory system, which refers to a mechanism for temporarily maintaining and manipulating information. This WM model consists of two basic short term stores (the phonological loop and the visuospatial sketchpad), and a central executive system. The phonological loop and visuospatial sketchpad refer to temporarily storing auditory and visual/spatial stimuli respectively. The CES acts as an attentional controller that controls, regulates, manipulates and integrates information. Such functionality is usually required in complex cognitive tasks such as multitasking. Thus, PET relies on two main assumptions. The first assumption is that worry and arousal as a manifestation of neuroticism/trait anxiety cause impairment during WM task processing. The second assumption is that the impairment is associated with the CES whereas it is not associated with the storage systems of WM.

The first assumption suggests that the main causes of task impairment in high neurotics are worry and higher arousal level, which lead to greater task irrelevant activities in demanding WM task processing, because worry and arousal level are increased by stressful situations (M. W. Eysenck & Calvo, 1992). In detail, according to Kehman (1973) and Sarason (1988), greater worry and arousal level leads to higher task irrelevant activities during cognitive processing. Because in high neurotics worry and arousal level easily increase, the task demand is higher for high neurotics than low neurotics (Sarason, 1988; Sarason, Sarason, & Pierce, 1990). Consequently, high neurotics have to deal with task related information as well as task irrelevant mental activities, and therefore they perform worse than low neurotics on WM tasks (M. W. Eysenck & Calvo, 1992; Revelle & Michaels, 1976). Cognitive resources have to be shared between task irrelevant activities and task related information, and therefore task processing may be impaired due to a scarcity of cognitive resources (Sarason, 1988). Taken together, the reason why high neurotics demonstrate slower task processing is because worry and a higher arousal level cause task irrelevant mental activities that overlap with the task relevant activities (M. W. Eysenck & Calvo, 1992).

The second assumption is focused on the components of working memory. It is suggested that the adverse effect of neuroticism (i.e. worry, arousal) cause extra demand on some working memory components only (M. W. Eysenck & Calvo, 1992). The considerable detrimental effects of neuroticism have an impact on the central executive system rather than on other storage components (M. W. Eysenck & Calvo, 1992; M. W. Eysenck & Byrne, 1992). The reason why neuroticism mainly impairs CES is because worry interferes with attention (M. W. Eysenck & Calvo, 1992; Studer-Luethi et al., 2012). As indicated, the CES is like an attentional controller (Baddeley, 1996a), and thus it requires higher sustained attention (M. W. Eysenck & Calvo, 1992; Studer-Luethi et al., 2012). When task demand increases, worry causes task irrelevant activities (worrisome thoughts) that overlap with task relevant activities during the processing of resources (Flehmig et al., 2010; Sarason et al., 1990). Because the resources of the WM system are consumed by task irrelevant activities, processing of the task is impaired (M. W. Eysenck & Calvo, 1992; Flehmig et al., 2010; Sarason et al., 1990). In other words, a higher proportion of attentional resources are allocated for the CES, and as a consequence task processing is impaired when task difficulty is associated with the CES (M. W. Eysenck & Calvo, 1992). Empirical studies show that if two tasks are associated with the CES, then high neurotics have a greater impairment than low neurotics, compared to when performing two VSSP tasks in high and low neurotics (M. W. Eysenck et al., 2005; MacLeod & Donnellan, 1993). (Related empirical studies will be presented in section 1.5.1).

Furthermore, because worry is supposed to be related to inner words (M. W. Eysenck & Byrne, 1992), the phonological loop storage may also have a minor impairment but the visuospatial sketchpad may remain unaffected (M. W. Eysenck & Byrne, 1992; M. W. Eysenck & Calvo, 1992). One potential reason for that is because worry involves in inner words activity, which may contribute to task irrelevant activities rather than encoding visual representations in the VSSP (M. W. Eysenck & Calvo, 1992).

Overall, according to the assumptions of PET, high neurotics are believed to be associated with worry, which physiologically causes a greater arousal level than in low neurotics (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992). Thus high neurotics are slower on WM task processing because their worry and arousal lead to task irrelevant mental activities that overlap with the task relevant activities. The other assumption is that the processing of WM tasks is impaired due to the load on the central executive system (M. W. Eysenck & Calvo, 1992). As a result, worry and arousal mainly influence the CES in high neurotics, and thus when task demand is associated with the CES, a considerable impairment is observed during task processing (M. W. Eysenck, 1985).

Although this theory proposes that the detrimental effect of neuroticism negatively influence CES, it does not include any assessment of the functions of the CES. As discussed earlier, the CES has various functions such as switching and inhibition. Relying on this theory, one cannot know whether the detrimental effect of neuroticism/trait anxiety disturbs all of these functions equally or just certain functions. Recent studies indicate that the lack of information about the functions of the CES in relation to neuroticism/trait anxiety is a weakness of the theory (M. W. Eysenck et al., 2007).

1.4.4 Attentional control theory (ACT)

Attentional control theory was proposed by Eysenck, Derakshan, Santos, & Calvo, (2007) and later developed by Derakshan & Eysenck, (2009). The theory was built on the strengths of PET and aims to overcome its weakness by providing more precise assumptions related to the impact of anxiety on the cognitive processing of the CES functions (M. W. Eysenck et al., 2007). Therefore, this theory includes the assumptions of PET in addition to new assumptions. The core of this theory is based on the assumption that arousal and worry, as a manifestation of neuroticism/trait anxiety, have a negative impact on attentional control, which leads to detrimental effects on the functions of the central executive system (Derakshan & Eysenck, 2009). This theory consists of several assumptions.

The first assumption of ACT relies on the differences between effectiveness of performance and efficiency of processing (Derakshan & Eysenck, 2009). Effectiveness of performance refers to the quality of the task performance such as response accuracy whereas processing efficiency addresses the association between higher accuracy (effectiveness of the performance) and faster response times (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). Thus, processing efficiency requires using resources or effort optimally (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). According to Flehmig et al. (2010) the relationship between processing efficiency and performance effectiveness is based on a speed accuracy trade-off, which indicates the interaction between response times and error rates (i.e. sacrificing speed for accuracy). High neurotics may spend higher effort on achieving the task accurately by sacrificing speed or vice versa (Flehmig et al., 2010). In this context, high neurotics still have lower processing efficiency because they use a larger amount of cognitive resources to achieve the task either more accurately or faster by ignoring either speed or accuracy (Flehmig et al., 2010; Szymura & Wodniecka, 2003). For example, one study reported that high neurotics become slower on a task processing as expense of accuracy (Flehmig et al., 2010; Szymura & Wodniecka, 2003) and another study reported slower reaction times with higher accuracy (Robinson & Tamir, 2005). The results can be explained by the speed accuracy trade-off. In other words, their strategy is, performing task either accurately or faster therefore their attention is increased on either accuracy or speed whereas they ignore one of the them (e.g. when they focus on accuracy they ignore speed) (Flehmig et al., 2010). However, in processing efficiency, speed and accuracy are balanced and they will be high if performance effectiveness (accuracy) is greater with faster response times as indication of using cognitive resources efficiently (M. W. Eysenck et al., 2007). On the other hand, processing efficiency will reduce if performance effectiveness is low (lower accuracy) with slower RTs as an indication of a higher usage of resources (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). Thus, greater processing efficiency reflects faster RTs with higher accuracy (M. W. Eysenck et al., 2007). Taken together, according to the ACT it can be assumed that high neurotics will have a greater impairment in processing efficiency than in performance effectiveness because of task irrelevant activities in demanding WM tasks (Derakshan & Eysenck, 2009; Derakshan & Eysenck, 2010; M. W. Eysenck et al., 2007). This is important to understand because significantly higher accuracy with a slower speed or vice versa indicates using a speed accuracy trade-off strategy than higher processing efficiency.

Therefore, when the experimental results are assessed regarding task processing, one has to consider this point.

The second assumption concerns two attentional systems; top-down and bottom up processes (M. W. Eysenck et al., 2007). The top down goal driven system is associated with the prefrontal lobe and it is involved in the regulation of attention whereas the bottom-up stimulus driven system is associated with the temporal-parietal and ventral frontal cortex and it is involved in the determination of relevant stimuli, especially when the stimulus is salient and unattended (Derakshan & Eysenck, 2009). Accordingly, there is often a stable interaction between the top down and bottom up systems (Pashler, Johnston, & Ruthruff, 2001). However, according to ACT, in high neurotics, the stable interaction of the system is impaired due to neuroticism because worrisome thoughts enhance the impact of the bottom up process over the top down process (M. W. Eysenck et al., 2007). For example, regarding high neurotics, under demanding conditions, an increased level of worry and arousal may awaken an anxiety state, and thus one will fail to supress task irrelevant activities that negatively influence task processing (Power & Dalgleish, 1997). Therefore, the focus of attention increases towards task irrelevant mental activities (M. W. Eysenck et al., 2007; Power & Dalgleish, 1997). Thus the anxiety state will cause pressure on goal directed systems in favour of stimulus directed systems (M. W. Eysenck et al., 2007). This assumption helps in understanding a potential reason for task impairment in high neurotics.

The third assumption relates to the functions of the CES in relation to effect of neuroticism (M. W. Eysenck et al., 2007). Accordingly, the detrimental effects of neuroticism have an impact on certain CES functions rather than storage components because task irrelevant activities interfere with attention during the processing of information (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Furthermore, because worrisome thoughts are supposed to be related to inner words, the phonological loop storage may also have a minor impairment (M. W. Eysenck et al., 2007). The reason for that is that worry is associated with verbal activities, and thus worrisome thoughts may influence the processing of resources by interfering with attention (M. W. Eysenck et al., 2007). On the other hand, the visuospatial sketchpad is supposed to remain unaffected because worry does not usually involve storing visual and spatial representations (M. W. Eysenck et al., 2007). Although PET suggests that worrisome thoughts impair cognitive processing in the CES, it remains relatively imprecise because the CES is responsible for carrying out various functions including the following: task coordination, manipulation, shifting attention between tasks, and monitoring and updating the context of working memory tasks (M. W. Eysenck et al., 2007; Smith & Jonides, 1999). Therefore, it is significant to consider which functions are actually impaired due to the effect of neuroticism during the cognitive processing of the task. The predictions of ACT try to shed light upon this aspect of CES functions (see Eysenck, et al., 2007). To explain this mechanism in more detail, Eysenck, et al., (2007) referenced a model developed by Miyake, Friedman, et al., (2000) and Friedman & Miyake (2004). As described in section 1.3, Miyake et al. (2000) found evidence for three main functions of the central executive system: inhibition, switching and updating (see Eysenck, et al., 2007; Friedman and Miyake 2004). First, inhibition refers to the suppression of task irrelevant stimuli that can potentially cause interference (M. W. Eysenck & Derakshan, 2011). In other words, inhibition is supposed to work when a dominant or automatic response needs to be supressed (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). This is called negative attentional control (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). Second, the switching function refers to flexibility in shifting attention between two tasks, operations or mental sets (Derakshan & Eysenck, 2009). Third, the update function refers to refreshing and monitoring mental representations during the processing of tasks (Derakshan & Eysenck, 2009; Miyake et al., 2000). According to ACT, the inhibition, switching and updating functions of the CES are impaired rather than other CES functions due to high neuroticism (arousal, worry) during the processing of demanding cognitive tasks (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). However, because the updating function is associated with short term memory storage as well, the impairment would be rather minor or indirect on this function (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). As a result, arousal and worry as a manifestation of high neuroticism have adverse effects on attentional control and these adverse effects result in the impairment of the aforementioned functions, particularly the switching and inhibition functions (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). This is probably the most important assumption of ACT. When the experimental paradigm is set up, this assumption has to be considered in order to understand the processing of a demanding task in high neurotics.

Finally, originally ACT proposed, the detrimental effect of neuroticism on WM task processing causes increased activation in the cognitive control regions such as the LPFC (DLPFC and VLPFC) (M. W. Eysenck et al., 2007). However, this assumption could not be confirmed by the empirical studies (Bishop, 2007; Bishop, 2009; Braver, Gray, & Burgess, 2007) because it has been suggested that high neuroticism/trait anxiety leads inefficient recruitment of cognitive resources which leads decreased activations in cognitive control regions (Bishop, 2009; Dima et al., 2015). Following the study of Bishop (2009) which found decreased activation during N-Back task in high neurotics, ACT (M. W. Eysenck & Derakshan, 2011) suggests, if high neurotics do not put sufficient effort into the task, they may show decreased activations as compared with low neurotics. I will assess the empirical evidence in detail in 1.5.2.

As a summary, ACT provides detailed assumptions regarding cognitive processing in relation to neuroticism/trait anxiety. Greater task impairment may be observed in high neurotics. Worry increases the arousal level, which increases task irrelevant activities in high neurotics. Task irrelevant activities interfere with attention and thus high neurotics are inclined towards a bottom up goal driven system. It is assumed that the detrimental effect of neuroticism impairs three main functions (switching, inhibition and updating). When task processing is assessed, processing efficiency should be considered rather than performance effectiveness. Regarding this thesis, these predictions are quite important because when I design the experimental paradigms and assess the results, these assumptions should be considered in order to understand the detrimental effect of neuroticism in task processing.

1.4.5 Dual mechanism of Control (DMC) theory

Braver, et al. (2007) suggested a theory called dual mechanisms of control, which includes two distinct control mechanisms regarding cognitive processing during a demanding task. Proactive control is believed to be associated with the early selection of attentional focus, which refers to the selection of task related information without delay and processing it with limited capacity (Braver et al., 2007). For example, the maintenance of goal related information, response preparation and other task requirements are selected and processed during the processing of a demanding task (Fernandez-Duque & Johnson, 1999). Thus, it represents sustained representation of task relevant goals (Fernandez-Duque & Johnson, 1999). In other words, the focus of attention is on task related information when the proactive control mechanism is active (Braver et al., 2007). Therefore, if one is inclined to use the proactive mechanism, task processing will be efficient (Braver et al., 2007). On the other hand, reactive control is believed to be associated with transient representations of stimulus related activities so it is activated only when needed such as a late correction character

(Braver et al., 2007). According to this theory, proactive control is associated with top down processes and reactive control is associated with bottom up processes (Braver et al., 2007; Braver, 2012). The top down goal driven system is linked with proactive control, is associated with the prefrontal lobe (cognitive control regions), and is involved in the regulation of attention (Braver et al., 2007; Braver, 2012). The bottom-up stimulus driven system is linked with reactive control and is associated with the temporal-parietal and ventral frontal cortex (Braver et al., 2007; Braver, 2012). It is involved in the determination of relevant stimuli, especially when the stimulus is salient and unattended (Braver et al., 2007; Braver, 2012). Accordingly, if participants encounter a conflict or difficulties because of task irrelevant activities in a demanding task, reactive control activities may be revealed temporarily to fix the difficulty during task processing (Braver, 2012). Therefore, the focus of attention will be on task irrelevant activities during demanding task processing (Braver et al., 2007; Braver, 2012). If one is inclined to use a reactive control mechanism, it is likely that a higher impairment in task processing will be observed because higher task irrelevant activities have to be suppressed first (Braver et al., 2007; Braver, 2012).

According to this model, high neurotics may have task impairment when task demand is associated with the CES such as dual tasks (Braver et al., 2007; Braver, 2012; Gray et al., 2002). The reason for that is because of using the control mechanisms in unstable way (Braver, 2012). For example, under a demanding condition increased arousal level and worry activate reactive control in high neurotics and thus they will first deal with task irrelevant activities that are threatening the task processing (Braver et al., 2007; Braver, 2012; Gray et al., 2002). Therefore, at first, they fail to employ cognitive resources for task related activities (Power & Dalgleish, 1997). In other words, their attention will increase to deal with the task irrelevant situation (that is threatening the processing task), and thus the detrimental effect of neuroticism will cause pressure on the proactive control system in favour of the reactive control system (Braver et al., 2007; Braver, 2012; Gray et al., 2002) .

DMC suggests lower neural activation in the cognitive control regions in high neurotics because of insufficient recruitment of cognitive resources (Braver, 2012). The reason for that is that high neurotics are more inclined to use the reactive control mechanism in demanding cognitive tasks (Braver, 2012). In detail, proactive control is associated with the cognitive control regions whereas reactive control is associated with default networks (i.e. medial PFC, posterior cingulate/precuneus, lateral parietal cortex, left inferior temporal lobe and the amygdala) (Braver, 2012; Broyd et al., 2009; Gray et al., 2002). The default network is suggested to be negatively correlated with attentional tasks (Braver, 2012; Broyd et al., 2009). In particular, when a cognitively demanding task has to be processed efficiently, which requires proactive control, the cognitive control regions are activated and the default network regions tend to be less active (Braver, 2012; Burgess & Braver, 2008; Drevets & Raichle, 1998). However, in high neurotics, the reactive control mechanism may increase activations in default regions and impair cognitive processing by supressing the activation of the cognitive control areas (Braver et al., 2007; Braver, 2012; Burgess & Braver, 2008; Gray et al., 2002).

Taken together, high neurotics are inclined towards reactive control and therefore in demanding tasks they perform worse during task processing because they cannot implement cognitive resources for task relevant activities. Low neurotics are inclined towards proactive control and therefore they select task relevant activities earlier on because they have a lower arousal level and less worry. Consequently, high neurotics have lower activation in the cognitive control regions compared to low neurotics during demanding cognitive tasks (Braver et al., 2007; Braver, 2012; Gray et al., 2002).

1.4.6 Summary of the theories in relation to neuroticism

In section 1.4., I introduced arousal based theory in relation to neuroticism (H. J. Eysenck, 1967), PET (M. W. Eysenck & Calvo, 1992), ACT (M. W. Eysenck et al., 2007) and DMC (Braver et al., 2007). Eysenck (1967) suggested that high neurotics perform worse than low neurotics on difficult tasks because of a higher arousal level compared with low neurotics. However, the definition of task difficulty was not assessed in this theory. PET (M. W. Eysenck & Calvo, 1992) suggests that high neurotics perform worse on WM tasks when task demand is associated with the CES because task irrelevant activities interfere with attention during the processing of tasks. This theory provides more detailed assumptions than arousal based theory of neuroticism (H. J. Eysenck, 1967). However, the theory (PET) evaluates the CES as a unitary system, and thus which functions of the CES are impaired by the detrimental effect of neuroticism is not assessed. ACT (M. W. Eysenck et al., 2007) is built on PET and provides more detailed assumptions about the detrimental effect of neuroticism on task processing. ACT suggests that high level neuroticism impairs certain functions of the CES, which are switching, inhibition and updating (M. W. Eysenck & Derakshan, 2011). The stable balance of the top-down and bottom up goal driven systems is broken in high neurotics because of higher arousal and worry so they are inclined towards the bottom up goal driven system (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). Therefore, high neurotics cannot implement cognitive resources for task related information early on, because they increase their attention towards task irrelevant activities (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). Consequently, task processing is impaired in demanding tasks, which leads to lower processing efficiency (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). High neurotics may spend higher effort achieving the task, and in this case they sacrifice either speed or accuracy (i.e. they may sacrifice speed for higher accuracy and thus they may have lower error rates with faster RT) (M. W. Eysenck et al., 2007). DMC (Braver et al., 2007) assesses task processing in high and low neurotics with proactive and reactive control mechanisms. Similar to the interpretation of ACT (M. W. Eysenck et al., 2007), high neurotics are inclined towards reactive control, which is linked to the bottom up goal driven system (Braver et al., 2007). Therefore, they focus on dealing with task irrelevant activities during demanding tasks because of a higher arousal level and worry (Braver et al., 2007; Braver, 2012; Gray et al., 2002). Low neurotics are inclined towards proactive control, which is linked to the top down goal driven system (Braver et al., 2007; Braver, 2012; Gray et al., 2002). Therefore, low neurotics successfully select and process task relevant activities because their arousal and worry level is lower than high neurotics (Braver et al., 2007; Braver, 2012; Gray et al., 2002). DMC indicates whether people use reactive control. If so, then lower neural activation in the cognitive control regions occurs whereas if they use proactive control higher neural activation occurs in the cognitive control regions during demanding task processing (Braver et al., 2007; Braver, 2012; Gray et al., 2002). Therefore, high neurotics can be expected to have lower neural activation during demanding WM task processing (Bishop, 2009; Braver et al., 2007; Braver, 2012; Gray et al., 2002).

1.5 Neuroticism and Working Memory: Empirical Evidence

In this section, I will present the behavioural and neuroimaging findings in relation to neuroticism and WM. In particular, because this thesis includes behavioural and one imaging PRP dual task experiments, I preferentially focus on dual task studies.

1.5.1 Behavioural evidence about neuroticism related differences during cognitive processing of WM tasks

This section consists of two subsections. In the first subsection, I discuss studies that specifically investigated neuroticism related differences in WM task processing. I develop the discussion through the results and their possible limitations. In the second subsection, I discuss studies conducted with normal participants in terms of neuroticism related differences. I discuss their results in terms of neuroticism based on the theoretical background.

1.5.1.1 Empirical studies related to WM task processing in high and low neurotics

In this subsection, I have divided the studies into two groups. The first group of studies suggests that high neurotics have considerable impairments in dual tasks whereas high and low neurotics perform similarly on single and easy tasks. In the second group of studies, I assessed some studies that include inconclusive results. Also, I discuss a few studies that found either no relationship or a positive relationship between task performance and neuroticism level.

The majority of studies found a detrimental effect during the processing of cognitive tasks associated with a high level of neuroticism. For example, according to Eysenck, (1982), high neurotics perform similarly to low neurotics on relatively easy tasks such as visual search tasks or basic mathematical problems whereas if task demands are increased such as in WM tasks, this will diminish cognitive processing in high neurotics. In line with that, Cox-Fuenzalida, Swickert, & Hittner, (2004) probed the effect of neuroticism on vigilance task processing with 194 participants by manipulating the tasks from simple to complex tasks. Participants were required to perform an auditory vigilance task, which consisted of a sequence of digits that were presented by way of earphones. They were instructed to find odd–even–odd sequences of digits (the signal, e.g. 7–8–3). In the easy task, participants were given 2s for digit determination whereas in the difficult task they were given 0.8s. As a result, while the high neurotics performed better than the low neurotics on the simple task, their performance was significantly impaired in the difficult task. Further studies found similar results regarding the adverse effect of neuroticism on monitoring and vigilance task performance i.e. when task presentation is speeded (Mayer, 1977), AB tasks (a letter string task and a colour recognition task) (MacLean & Arnell, 2010), and probe colour tasks i.e. when the set size is only moderately increased (Bredemeier, Berenbaum, Most, & Simons, 2011).

While the above studies used a variety of different simple and difficult tasks, there is also more specific evidence from dual-task studies that supports the adverse effect of neuroticism in relation to cognitive processing. Because each dual task study has a different paradigm, I consider it helpful to present a few studies here. For example, Poposki et al., (2009) tested 152 subjects to investigate the relationship between neuroticism and extraversion personality trait on multitasking performance. Participants performed four different tasks that were presented at the same time. Participants completed the tasks one by one. After task completion they filled out a survey that asked them how anxious or tense they felt during the multitasking performance. The authors concluded that neuroticism causes detrimental effects on multitasking performance and the effect is mediated by anxiety. Similarly, Osorio et al., (2003) investigated the effect of neuroticism on selective attention by performing a kind of dual task experiment. Participants listened to a paragraph with one ear, and a word list with the other ear. The 87 subjects were required to iterate the paragraph that was presented to one of their ears and at the same time they were requested to ignore the words that were presented to the other ear. Both the paragraph and word list included stressful (emotional) and neutral versions. While performing this task, they were also asked to respond to a visual probe task. The authors indicated that the performance in low neurotics was not diminished by the distractor task, while the high neurotics were somehow negatively influenced by the distractors. Also, the impairment was higher when the task included stressful distractors. The high neurotics performed worse than the low neurotics on the dual task and using emotional stimuli may exacerbate the impairment in high neurotics. Studer-Luethi et al., (2012) investigated the influence of neuroticism and conscientiousness on n-back dual task processing with 112 participants. Participants performed the n-back task as a single task. However, in the dual task, they performed a visual n-back task (which included sequential presentation of single blue squares at one of eight different locations on the computer screen) and an auditory task (which included a series of 8 letters). Although the participants were trained on task performance, neurotics, compared to the controls, were found to have lower processing efficiency (higher RTs and error rates) in the task processing of demanding dual tasks whereas they were more successful in accomplishing single simple tasks. Further dual task studies in relation to neuroticism with different experimental designs produced similar results (Corr, 2003; M. W. Eysenck & Nazanin, 1998; Leon & Revelle, 1985; Poposki et al., 2009; Studer-Luethi et al., 2012; Szymura & Nęcka, 1998; Szymura & Wodniecka, 2003).

Taken together, the first group of studies found that neuroticism impairs working memory during dual tasks and in other demanding WM task processing (Corr, 2003; M. W. Eysenck

& Nazanin, 1998; Leon & Revelle, 1985; Poposki et al., 2009; Studer-Luethi et al., 2012; Szymura & Nęcka, 1998; Szymura & Wodniecka, 2003) whereas neuroticism has no adverse effects on simple and easy tasks (Corr, 2003; Studer-Luethi et al., 2012; Szymura & Nęcka, 1998; Szymura & Wodniecka, 2003) because performing an easy task is not stressful (H. J. Eysenck, 1967).

I should point out that a few of the studies that are indicated above include inconclusive results as well. These studies usually performed a series of behavioural experiments. While some of the experiments resulted in findings that are in line with my statements, one or two of the experiments remained inconclusive. For example, Szymura & Necka (1998 & 2003) probed both high level neuroticism and extraversion traits (high extraversion participants were taken as low neurotics) regarding the processing of a single task and multitasking conditions. In the single task they used a DIVA probe test (i.e. which is a signal detection task that includes one target letter and other letters as distractors) only (Szymura & Wodniecka, 2003). Each probe letter was presented either for 650ms or 850ms or 1000ms to create stressful and easy conditions in the latter study. In the dual task the participants performed probe tasks and a falling bar task. The participants were required to respond to the appropriate letter on the screen while they controlled the position of a falling bar up in the middle by pressing mouse buttons. In the dual task condition, the set size changed from 3 to 5 letters. Although their first experiment revealed non-significant results between the groups both in terms of the response latencies and response accuracy, subsequently the majority of the experiments revealed significant results generally in terms of response accuracy. In one experiment, when they increased the set size in the dual task condition, the high neurotics had higher response latencies and error rates. One potential reason for such results in the first experiment might be the speed accuracy trade-off strategy (Flehmig et al., 2010). Because the first dual task experiment was rather easy the high neurotics performed similarly by spending higher effort. In the subsequent experiments, the task difficulty increased respectively (M. W. Eysenck et al., 2007). In the first tasks, high neurotics may focus on RTs during the task performance as a strategy so that they did higher number of errors and they were still not better than low neurotics regarding RTs as well. In the last experiment, the task difficulty increased by set size and by stimuli presentation time (i.e. 1000 ms and 650ms) (M. W. Eysenck et al., 2007). Because this experiment was rather difficult, the worry and arousal levels exceeded the activation threshold in the high neurotics (see section 1.4.1) (H. J. Eysenck, 1967), and thus despite using the speed accuracy trade-off strategy they had higher errors and RTs. From this point of view, the results are in line with both the arousal based theory of neuroticism (H. J. Eysenck, 1967), which suggests an activation threshold for arousal, and ACT (M. W. Eysenck & Derakshan, 2011), which suggests lower processing efficiency in high neurotics. Therefore, in both series of experiments the authors concluded that the high neurotics had lower processing efficiency compared to the low neurotics in terms of multitasking performance. Moreover, in a series of experiments, Corr (2003) investigated whether neuroticism influences procedural learning during dual task conditions. Participants performed a procedural learning task as a single task whereas in the dual task condition they performed a procedural learning task with either a mental arithmetic test or a nonsense syllable count task concurrently (Corr, Pickering, & Gray, 1995; Corr, 2003). While one experiment showed a higher impairment in high neurotics compared with low neurotics regarding RTs and error rates, the results could not be replicated in the subsequent experiments. Generally, it was concluded that while procedural learning remained intact under the single task condition, it was impaired under the dual task condition specifically in high neurotics (Corr, 2003). According to Corr, (2003), the reason why the result could not be replicated in the second experiment is because the task experiment was not demanding, so the participants could easily perform the task due to a lack of sufficient stressors. Another study that can be assessed as inconclusive was conducted by Robinson and Tamir (2005). The authors conducted a series of choice RT task experiments. They found no correlation between elevated levels of neuroticism and either means RT or response accuracy. However, a significant positive correlation was found between elevated neuroticism and the RT standard deviation. Thus, they concluded that task irrelevant activities lead to deficits during the processing of tasks in high neurotics. According to the authors, RTs positively correlated with standard deviation (i.e. slow = more variable) and it can be an indicator of efficient task processing. Because the standard deviations of the RTs are stable during task processing, it is a good indicator of individual difference in the study sample. Therefore, the results are more likely to show lower processing in high neurotics than in low neurotics. Taken together, despite the occasional odd findings, the general conclusion of these studies was support for the adverse effect of neuroticism on dual task processing. Therefore, the studies seem to be in line with the arousal based theory of neuroticism (H. J. Eysenck, 1967) and ACT (M. W. Eysenck et al., 2007). The reason why high neurotics did not differ in terms of task processing might be because the task was not enough difficult. Therefore, when task processing in high and low neurotics is investigated, the task difficulty factor should be considered.

In contrast to the aforementioned findings, one study, an unpublished doctoral dissertation, found no association between high and low neurotics during cognitive processing of WM tasks regarding RTs and accuracy (Delbridge, 2000). In this study participants performed three tasks (a reference task, a situational judgment test, and a logic puzzle-solving test) sequentially in a certain time. The author assumed that personality traits would predict multitasking performance due to task irrelevant activities. In particular, neuroticism is assumed to be highly correlated with deficits in multitasking performance. However, the hypothesis could not be confirmed because a high level of neuroticism was not found to be associated with impairment to multitasking performance. In contrast to other studies, this study suggests that high and low neurotics do not differ on cognitive task processing. According to Delbridge (2000), the nonsignificant results may be because of methodological issues in this study. The task may not have been demanding enough because the participants were given a longer time to perform the tasks sequentially.

Interestingly, one study found that high neurotics were worse regarding accuracy but better regarding RTs compared to low neurotics during cognitive task processing. Flehming et al., (2010), recruited 99 participants to test the reaction time in neurotics during serial mental addition and comparison tasks. Participants were asked to find out the result of the addition task and they had to decide whether the number was larger or smaller than another number next to the addition task by pressing specified buttons. In contrast to the previous findings, they found that high neurotics processed the task faster than low neurotics. However, at the same time, high neurotics made more errors. These results can be interpreted based on 'narrowing attention' which is proposed by (Easterbrook, 1959). According to Easterbrook, (1959) the high neurotics may have focused on only a certain part of the task by narrowing their attention. For example, they may have ignored accuracy and focused on RTs as a speed accuracy trade-off strategy (Flehmig et al., 2010; Szymura & Wodniecka, 2003). They may have used a different speed-accuracy criterion, but their "overall performance" (processing efficiency) might have been the same (Flehmig et al., 2010). Thus, they were not necessarily better at all (Flehmig et al., 2010; Szymura & Wodniecka, 2003). Therefore, high neurotics may narrow their attention to accomplish a task faster but they might neglect accuracy (Szymura & Wodniecka, 2003).

However, there are several important questions regarding set size, task priority, neuroticism scores and sample size in terms of the aforementioned studies, which may have caused such inconsistency in the results. For example, generally, the studies manipulated the set size to create easy and difficult multitasking conditions (Cox-Fuenzalida, Swickert, & Hittner, 2004; Szymura & Wodniecka, 2003). However it is not assessed whether an increased set size (i.e. in the number of letters) led to increased demand on the central executive system or working memory storage. Therefore, the question is, do high neurotics achieve lower response accuracy or higher reaction times due to the load on their working memory in terms of short term storage or the central executive functions? Secondly, some studies do not indicate which task was the primary task and which was the secondary task (e.g. Szymura and Wodniecka 2003; Corr 2003; Studer-Luethi, Jaeggi, Buschkuehl and Perrig, 2012). The response order in task processing is important because this allows for understanding whether the primary task or secondary task was impaired in dual task processing. There is an argument about response order in relation to neuroticism. For example, Easterbrook (1959) suggested that the secondary stimulus was impaired in high neurotics, because they focused on the first task due to narrowing their attention (i.e. first come, first served). Accordingly, the detrimental effect of neuroticism increased their attention on first task and thus the second task was ignored. On the other hand, ACT suggests that task impairment depends on the saliency of the task (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). If the first task is salient and the second task is periphery, then the second task is impaired (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). If the second task is the most salient, then the first task will be impaired (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Thirdly, they did not use selective samples because the neurological and psychiatric history of the participants, their current mood state, and their consumption of alcohol or caffeine were not assessed as exclusion criteria. (Studer-Luethi, et al., 2012; Szymura & Wodniecka, 2003 but see Chan, et al., 2007). It is important to consider the exclusion criteria because arousal level may be influenced by caffeine, alcohol, or mood state in high neurotics. For example, it has been found that caffeine may have an additive effect on neurotics so the consumption of caffeine may damage their performance (Craig, Humphreys, Rocklin, & Revelle, 1979). Also, participants' history in terms of psychiatric and neurologic disorders may considerably affect the reliability of a study (i.e. depressed participants probably will be high on the neuroticism scale as well, and in this case we cannot know whether the impairment is because of neuroticism or depression (Chan et al., 2007; Chan et al., 2008). Furthermore, in some studies, participants were randomly invited and took personality tests and the median of the neuroticism scale across the sample was used to divide the participants into two groups, high (i.e. scores over 12 on the neuroticism scale) and low (i.e. scores below 12) neurotics (see Corr, 2003; Osorio, et al., 2002; Robinson &

Tamir, 2005; but see Szymura & Wodniecka 2003). For instance, although scores over 12 might be reasonable for high neurotics, scores below 12 are quite high to classify people as low neurotics, because people who score over 10 on a neuroticism questionnaire may show neurotic symptoms (Chan et al., 2007; H. J. Eysenck, 1991; H. J. Eysenck, 1967). Therefore, moderate neurotics were also placed in low neurotic groups (H. J. Eysenck, 1991; H. J. Eysenck, 1967). This may be one of the crucial factors that may negatively affect the reliability of some of the findings. Therefore, in this thesis I will deal with these problems as well.

So far, generally, the literature has demonstrated that a high level of neuroticism is associated with impairment in difficult, stressful or demanding working memory tasks due to neuroticism related effects (Braver, 2012; H. J. Eysenck, 1967; M. W. Eysenck et al., 2007). The question is then, what kinds of task demands in WM tasks are really demanding for neurotics? Or what stimulation conditions can cause impairment in the central cognitive mechanisms of neurotics? To my knowledge there is no study that answers these questions specifically regarding neuroticism. Although in a few dual task studies that are related neuroticism, the results interpreted based on ACT (M. W. Eysenck et al., 2007) and PET (M. W. Eysenck & Calvo, 1992), they did not assess these CES functions in relation to the detrimental effect of neuroticism. Therefore, for a reasonable explanation, I have utilised a few studies that investigated task demand and the central executive mechanism with normal and non-selective samples. To investigate the integration between task demand and neuroticism, I first investigated general task demand and WM task demand. Subsequently, I presented task demand in WM components i.e. in the CES and in the storage systems.

1.5.1.2 Empirical studies that are useful for the current study

Previous empirical studies with normal participants have demonstrated a disassociation between WM task demand and general task difficulty in WM tasks. Accordingly, task difficulty can be increased without increasing the demand in WM and thus that type of task difficulty disassociated from WM task demand. For example, Barch, et al. (1997), conducted a functional magnetic resonance imaging (fMRI) study to examine the disassociation between demands placed on working memory and increased task difficulty in other processes apart from working memory. Eleven healthy participants performed probe tasks. Participants were required to respond to the letter ‘X’ but only when it followed the letter ‘A’ among a series of letters. Working memory demand was higher when the time interval was short between letters and lower when the time interval was longer. Furthermore, they degraded stimuli by removing %80 of pixels from the image of the letters to increase the task difficulty, which is particularly related to perceptual process and not working memory demand. Accordingly, the authors found that a higher task demand for both the degrading task and WM demands was associated with slower reaction times and higher error rates but the influenced brain areas were dissociated. Demand on working memory leads to an impairment in processing tasks and is reflected as higher dorsolateral prefrontal lobe activation. However, increased task difficulty by stimulus degradation resulted in higher activation in the anterior cingulate, and other regions of the frontal cortex. These results show the disassociation between general task difficulty and specific task demand placed on WM. The results indicate that task difficulty and WM demand similarly affect performance (Barch et al., 1997; Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008). However, they are disassociated and thus task difficulty by degrading stimuli is associated with a perceptual process whereas WM demand is associated with the CES (Barch et al., 1997). Therefore, task difficulty, even placed outside of working memory, influences task processing in non-selective healthy samples. However, this should not be the case for differentiating high and low neurotics because it has been indicated that arousal and worry impairs the CES in high neurotics (see section 1.4.5). At this point, one may suggest that if task processing is affected by arousal, anxiety or stress, any type of task difficulty could trigger stress or anxiety, which impairs task processing in high neurotics. When the ACT assumption (M. W. Eysenck et al., 2007) about the CES is considered, any task difficulty will result in stress, but in high neurotics, greater stress affects only the CES-functions. As a potential result, if task difficulty is increased by degrading stimuli, both high and low neurotics should have higher RTs and error rates in degraded tasks compared to non-degraded tasks but the results should not differ between high and low neurotics (the interaction would be nonsignificant). One of the experimental conditions in this thesis will relate to the disassociation between task difficulty and CES demand in high and low neurotics.

Although these kinds of investigations i.e. stimuli degradation (Barch et al., 1997) have not been done in high and low neurotic samples, as I discussed in section 1.4.5 an assumption of ACT (M. W. Eysenck et al., 2007) is that arousal and worry, which are associated with neuroticism, will impair the central executive function. Accordingly, task processing is influenced only when task demand is increased on the central executive component of working memory (mainly the shifting, inhibition and updating functions). Here, I discuss the empirical evidence in favour of this assumption. The evidence comes from anxiety studies that include switching tasks (i.e. WCST) and dual tasks. For example, one of the tasks for testing the shifting function is the WCST and the Comprehensive Trail Making Test (CMT). Studies on these tests usually demonstrate that high trait anxiety subjects execute higher errors and they are slower than low anxiety trait subjects (Derakshan, Smyth, & Eysenck, 2009; M. W. Eysenck et al., 2005; Goodwin & Sher, 1992; Orem, Petrac, & Bedwell, 2008). Furthermore, various dual task studies have found an adverse effect of trait anxiety associated with task demand in the central executive system but not the storage system. In these studies, participants performed a corsi block task concurrently with another task related to either the phonological loop, visual sketchpad or CES (M. W. Eysenck et al., 2005; MacLeod & Donnellan, 1993). The results show that task processing is considerably impaired only when one of the tasks is associated with CES. For example, Eysenck, Payne, & Derakshan (2005) conducted a dual task study with high and low anxiety groups. Participants performed a corsi block task concurrently with one of the following tasks: articulatory suppression (PL); counting backwards (CES); or spatial tapping (VSSP). Task processing was impaired in the high anxious group when they performed the corsi block task only with the second task, which was related to the central executive system. The results show that high anxiety only impaired the function of the central executive system whereas the storage system remained intact.

I will use the PRP paradigm to test the effect of neuroticism on the CES functions. As discussed (see section 1.3.3.), single tasks are simple and do not require much executive functions whereas dual task processing requires extensive use of the CES function (De Jong, 1995b; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997b; Szameitat et al., 2016). Importantly, task processing in single and dual tasks will allow for seeing the effect of neuroticism in CES and non-CES tasks. Regarding the PRP dual task paradigm, another way to increase demand only on functions of the CES would be manipulation in task order coordination which is called random dual task conditions (Szameitat et al., 2002). Accordingly, in this paradigm, participants need to rearrange and control the processing order permanently in order to perform the dual tasks in the correct temporal order (De Jong, 1995b; Stelzel et al., 2008a; Szameitat et al., 2002). Although this approach has not been tested in neurotic samples, it has been shown that it is strongly related to the central executive function in non-selective healthy participants (De Jong, 1995b; Stelzel et al., 2008a;

Szameitat et al., 2002). Another way to examine working memory components would be the manipulation of stimuli response (S-R) mapping (Stelzel et al., 2008a). By increasing the S-R mappings the CES demand could be increased, because response selection is a decisional process that requires the CES (Szmalec et al., 2005). Increasing the S-R mapping also makes the decision more difficult because there are more options to choose from among the stimulus (Stelzel et al., 2008a; Szmalec et al., 2005). It is commonly assumed that the components of a task set, including the stimulus and response sets, the task rules, and the task context, have to be maintained in an active state of working memory when behavioural tasks are performed (Cowan, 1999; Miller, 2000). Taken together, increasing S-R mapping places demand on the CES because it is a decisional process (Stelzel et al., 2008a; Szmalec et al., 2005). In this context, lower processing efficiency might be observed in high neurotics in higher S-R mapping dual tasks performance than in low neurotics.

So far, I have discussed several studies in terms of neuroticism. Considering the studies that have investigated the effect of neuroticism on the cognitive processing of tasks has several limitations. First, although the majority of the studies demonstrate that high neurotics performed worse than low neurotics, they do not explicitly describe which component of working memory, CES, PL, and/or VSSP, is mostly influenced by a high level of neuroticism (M. W. Eysenck et al., 2007; Szymura & Wodniecka, 2003). Second, the role of neuroticism in relation to the three main CES functions (shifting, inhibition and updating) has not been assessed (M. W. Eysenck et al., 2007). Third, although a few studies indicate that a high level of neuroticism impairs performance during dual task processing, they do not address which tasks are most impaired, either Task 1 or Task 2, or both equally (LeMonda et al., 2015; Szymura & Wodniecka, 2003). Fourth, although it is assumed that demands on the central executive functions will lead to detrimental effects on the cognitive processing of tasks (M. W. Eysenck & Derakshan, 2011), task difficulty, which is disassociated from working memory demands, has not been tested. For example, what happens when stimuli are perpetually adjusted to be more difficult, such as degrading stimuli (Barch et al., 1997)? In this thesis, I will consider these limitations as well, and thus I aim to tackle these problems by using the PRP dual task paradigm. (See section 1.3.3. for the task order in PRP and demand manipulation in relation to the CES functions in the PRP paradigm; See also 1.3.4 about general task difficulty and WM demand). For example, I compare single (non-CES) and dual task (CES) processing in high and low neurotics with an explicit task order. Furthermore, I manipulate the task demand on CES functions through parametric manipulation (random task) and S-R mappings. To test effect of neuroticism on general task difficulty, which is disassociated from the WM demand, I add a degraded stimulus in the dual task condition.

Most of the studies related to neuroticism seem to be partially in line with Eysenck's arousal based theory of neuroticism (H. J. Eysenck, 1967), processing efficiency (M. W. Eysenck & Calvo, 1992) and attentional control theory (M. W. Eysenck et al., 2007). However, the majority of those studies are unable to provide information about detailed analyses of the tasks, variability in the working memory load, task difficulty, or neuroticism without the effect of other neurological and psychological disorders (Corr, 2003; LeMonda et al., 2015; Szymura & Wodniecka, 2003). The study of the PRP dual task paradigm may help to shed light on this problem.

1.5.2 Neuroimaging Evidence about Neuroticism Related Differences during Processing of Working Memory Tasks

Studies related to the neural correlates of neuroticism related differences regarding cognitive processing are very rare (Dima et al., 2015; Dolcos & McCarthy, 2006) whereas there are plenty of studies regarding emotional processing (Baeken et al., 2009; Canli et al., 2001; Cunningham, Arbuckle, Jahn, Mowrer, & Abduljalil, 2010; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Reuter et al., 2004). Therefore, in addition to investigations in relation to neuroticism, I also provide evidence from anxiety studies, which can be divided into two groups of findings. While the first group of findings support the notion that neuroticism is associated with lower activation in the fronto-parietal areas during WM processing and a resting state compared low neurotics, the studies in the second group are a few in number and suggests the reverse (higher activation). To my knowledge, no studies have investigated the neural correlates of neuroticism related differences during dual task processing.

In the first group of studies, it has been shown that high levels of neuroticism result in decreased activation in the fronto-parietal regions. For example, Dolcos & McCarthy, (2006) investigated the effect of emotional and non-emotional distractors during the processing of a delayed-response working memory task regarding personality traits. In the delayed-response task there was one memoranda (a set of pictures including the probe picture), one probe picture, and distractors (neutral, scrambled, and negative). First, the participants were required to look at the memoranda to encode and maintain the pictures in their WM. Then, they were presented with one of the distractors. Finally, the probe picture was presented and they were required to decide whether they had seen the picture in the memoranda. As expected, decreased DLPFC (right BA 9, 46 and left 9) and VLPFC (right BA 45 and left 45, 47) activity (but stronger activity in the left regions) was found when the emotional distractors were threatening stimuli. It can therefore be interpreted that threatening emotional stimuli may increase the arousal level, which impairs task processing and reduces LPFC activity in cognitive processing. Recently, Dima et al., (2015) investigated personality related activations in the brain regions while participants performed 1, 2, and 3-N back WM tasks. Task related plasticity as effective connectivity is estimated by using dynamic causal modelling. The results showed that high levels of neuroticism result in decreased activation of the fronto-parietal executive control network, e.g. during a working memory 3 N-back task. Fronto-parietal connectivity links the right DLPFC to the right ACC and the right PAR, which are cognitive control regions. As discussed in section 1.3.4, the DLPFC and ACC are dissociable. While the DLPFC is associated with manipulation and maintenance, the ACC is activated when errors are executed in WM task processing (Baker et al., 1996; MacDonald et al., 2000). In this context, manipulation and maintenance are associated with the switching and updating functions respectively (De Jong, 1995b; Stelzel et al., 2008a; Szameitat et al., 2002) and error execution may be associated with the inhibition function (Baker et al., 1996; MacDonald et al., 2000). Therefore, these results seem to be in line with the ACT assumption in relation to the CES functions and neuroticism. In addition, it seems that in people with high levels of neuroticism the grey matter volume in the prefrontal areas (i.e DLPFC, ACC) is decreased (DeYoung et al., 2010; Kapogiannis, Reiter, Willette, & Mattson, 2013), and the prefrontal cortices are less strongly coupled with other areas by means of functional connectivity (Bjørnebekk et al., 2013; Servaas et al., 2015) during a resting state. Similarly, assuming that trait anxiety equates to neuroticism, several studies have found that trait anxiety involves inefficient activation of the cognitive control regions in the brain during WM task processing (i.e. probe tasks: detecting a target letter among the distractor letters) (Bishop, 2009; Bishop, Duncan, Lawrence, & Bishop, 2004). For example, Fales et al., (2008) investigated the neural correlates of anxiety during the cognitive processing of a 3N-back working memory task. The participant pool consisted of high and low trait anxiety groups. They watched emotional and neutral videos and then they performed the cognitive task in the scanner. The detrimental effect of trait anxiety was reflected in the cognitive control regions during the processing of the working memory task. High trait anxiety individuals were observed to have reduced sustained activity in the cognitive control regions, the right VLPFC (BA 47), compared to low anxiety individuals. The right VLPFC (BA 47) is also known to be associated with response inhibition and interference resolution (Aron, Robbins, & Poldrack, 2004; Badre & Wagner, 2005; Braver et al., 2007; Burgess & Braver, 2008). Accordingly, these results are in line with Bishop, (2007), who suggested that anxiety may impair processing efficiency due to insufficient recruitment of working memory resources. The lateral-prefrontal areas (DLPFC, VLPFC) and the ACC have frequently been associated with executive functions (Rottschy et al., 2012), and this is consistent with my argument above, that high levels of neuroticism are associated in particular with a deficit in the executive functions. These areas (i.e. DLPFC, VLPFC, ACC) are also known to be strongly involved in the top-down regulation of attention (associated with proactive control), particularly when task processing is needed for sustained attention (Fales et al., 2008). Neuroticism can increase attention on task irrelevant stimuli and reduce the focus of attention on concurrent task demands (Basten, Stelzel, & Fiebach, 2011; Bishop, 2009; Dima et al., 2015; M. W. Eysenck & Derakshan, 2011; Robinson & Tamir, 2005). Taken together, the cognitive control regions such as the DLPFC, VLPFC and ACC are associated with attentional control as part of the central executive system and they are influenced by neuroticism (Bishop, 2007; Dima et al., 2015; Fales et al., 2008). Higher task demand in cognitive tasks increases worry and arousal level, which causes higher task irrelevant activities. Because high neurotics tend to use a reactive control mechanism, they have to deal with task irrelevant activities as well as task relevant activities. Consequently, high neurotics have lower neural activation in the cognitive control regions due to a scarcity of cognitive resources.

On the other hand, the second group of studies failed to show lower activation in high neurotics and demonstrated that high neurotics have greater activation in the amygdala, ACC and parietal lobe such as during oddball task processing (Eisenberger et al., 2005), and in the amygdala and VLPFC during go-no-go task processing (Hare et al., 2008). For example, Hare et al., (2008) conducted a go-no-go task with adolescents with emotional instability who were supposed to be high neurotics. This task consisted of emotional images i.e. fearful and happy faces. Participants were required to respond to one type of emotional face i.e. fearful faces while they had to ignore other faces i.e. happy faces during the stimuli presentation. The results show increased activation in the amygdala and VLPFC in subjects who supposed to be high neurotics. There are two possible reasons for such results in task processing. One is regarding limbic system activations and the second is regarding PFC activations.

First of all, it is known that the presentation of emotional stimuli (i.e. a negative stimulus) is accompanied by higher amygdala activation in high neurotics (Canli et al., 2001; Chan et al., 2008; Di Simplicio, Norbury, Reinecke, & Harmer, 2014a; Haas et al., 2007). These studies show evidence of increased activation in the limbic system. Eysenck (1967) suggested that high neurotics have higher limbic system activation during stressful task performance (see section 1.4.1). The reason for that is, worry and an increased level of arousal, which may be related to emotional processes that influence the limbic system (Canli et al., 2001; Eisenberger et al., 2005). This assumption seems to be acceptable for emotional processing because high neurotics often show higher limbic system activation during the presentation of negative emotional stimuli (Canli et al., 2001; Eisenberger et al., 2005). Therefore, this assumption may be specified for emotional processing in high neurotics but not for cognitive processing because the cognitive studies that support this assumption are minor and consist of emotional cues.

Secondly, the task may not be difficult enough to show the detrimental effect of neuroticism. DMC suggests that high neurotics are inclined to use a reactive control mechanism that causes insufficient recruitment of WM resources, as is evidenced by lower activation in high neurotics (see section 1.4.5) (Braver et al., 2007). However, the inclination towards a reactive control mechanism in high neurotics does not mean that high neurotics always use a reactive control mechanism in all tasks (Braver et al., 2007; Braver, 2012). The task has to be demanding enough to increase the task irrelevant activities and thus high neurotics use reactive control while low neurotics use a proactive control mechanism (Braver et al., 2007; Braver, 2012). Consequently, the tasks in these studies that failed to show lower activation in the PFC may not have been demanding enough to reveal the detrimental effect of neuroticism, i.e. the high neurotics did not use a reactive control mechanism.

Taken together, the studies that show higher limbic system and PFC activation in high neurotics consisted of emotional stimuli and the tasks may have been found to be easy. Because the task demand was not high in these studies, high neurotics did not show lower activation in the cognitive control regions. Furthermore, because the tasks consisted of emotional stimuli high neurotics showed increased amygdala activation, which is not related to cognitive processing.

In summary, the empirical results demonstrate that a high level of neuroticism impairs the processing of WM tasks, which reflects decreased activation in the cognitive control areas such as the DLPFC, VLPFC and ACC. The studies that failed to show this pattern of results in high neurotics often used tasks that were not difficult enough to increase the arousal level and they were consisted of emotional stimuli.

1.6 Summary of Literature Review

Neuroticism refers to an inclination to negative affect and it taps the same features as trait anxiety (Jorm, 1989). It has been suggested that neuroticism negatively influences cognitive processing and thus it has a detrimental effect on WM and dual task processing (Studer-Luethi et al., 2012). The arousal based theory of Eysenck, (1967) suggests that high neurotics perform worse than low neurotics on difficult tasks due to a higher level of arousal. Furthermore, recently ACT (Eysenck et al., 2007) has suggested that the detrimental effect of neuroticism most likely influences the CES functions. To explore the CES functions in relation to neuroticism, the PRP dual task paradigm may be employed because generally it is very well investigated and thus it is understood theoretically and empirically. Regarding empirical studies, most of the previous research on neuroticism has focused on the effect of emotional cues and negative/positive memories in relation to neuroticism whereas research on working memory task processing in relation to neuroticism is limited. While several researchers are now implementing WM tasks, much of the related dual tasks remain relatively unexplored. Theoretically, it is suggested that a high level of neuroticism impairs the central executive system (M. W. Eysenck et al., 2007) and is accompanied by lower neural activation in the cognitive control network during cognitive tasks (Dima et al., 2015). Some investigations have highlighted the role of the detrimental effect of neuroticism during the processing of WM and dual tasks, yet it is unclear which component and function of WM is responsible for the decrements that occur due to neuroticism. Also, there is no study that shows what is occurring within the brain during dual task processing in high and low neurotics. It is important to gain a clear understanding of neuroticism related differences during the cognitive processing of dual tasks, especially if we assume that high-level neuroticism leads to deficits that contribute to poor dual task processing. To understand neuroticism in relation to working memory well validated standard tests can be used. Among the dual task methods, the PRP dual paradigm is a well-controlled paradigm and it fits neatly with Miyake et al.'s (2000) findings, which suggest that there are three main functions, switching, inhibition and updating. In this way, we can find where task impairments occur in high neurotics as compared to low neurotics.

1.7 The Current Study Outlines and Aims

In this section, I will outline my research aims, hypotheses, methods and results. Firstly, a brief introduction will be given regarding the general research aim, and the hypothesis and methods. Subsequently, a brief overview of each chapter will be presented. Finally, I draw a short conclusion regarding the current research in chapter 7.

1.7.1 Introduction to the current research

To investigate my current research, I asked the question, "What are the behavioural and neural correlates of neuroticism related differences during the processing of controlled cognitive tasks, particularly dual tasks?" Here, it is important to explain cognitive processes and why I preferred to use term 'controlled cognitive process'. Cognitive process refers to composition of mental operations which involve in thoughts, experience and the emotions. Generally, there are two categories of cognitive processing which is automatic and controlled processes. While an automatic process is capable of occurring without the need for attention, and the awareness of the initiation or operation of the process, and without drawing upon general processing resources or interfering with other concurrent thought processes, a controlled process controlled processes are defined as a process that is under the flexible, intentional control of the individual, that he or she is consciously aware of, and that are effortful and constrained by the amount of attentional resources available at the moment. For example a guitarist can play with guitar with an automatic process. Because working memory tasks and dual task performance requires attention and a considerable mental effort, in this thesis the term cognitive processing is refers to controlled cognitive processing.

Based on the information given above, the general hypothesis to be tested is that high neurotics will have lower performance in cognitive tasks which demands switching, inhibition and updating functions and will show lower neural activation in the fronto-parietal areas as compared to low neurotics. To that end, I conducted a series of experiments with high and low neurotics. The experimental findings of each chapter led to the design of the next study. Thus, the current research consists of seven chapters. The first chapter includes the literature review. The next five chapters are empirical chapters (the fifth: fMRi study), and the last chapter includes a general discussion and conclusion. In total this study consists of seven chapters.In chapter 1, I elaborate neuroticism related studies and potential studies that may be useful for investigating neuroticism in relation to cognitive processing. The assessment of the studies and current predictions is developed based on the related theories (i.e. arousal based theory of neuroticism, PET and ACT).

In chapter 2, I use a series of tests, SWM (VSSP), SOC (inhibition), and IED (switching and inhibition) associated with different functions or components of WM from the Cambridge Neuropsychological Test Automated Battery (CANTAB) by manipulating the task difficulty. I aim to investigate the behavioural correlates of individuals who scored high on the neuroticism scale in the cognitive processing of those Cantab tasks. One reason for the inclusion of the SWM is that I aim to test the specificity of the predictions in my design. In other words, I want to test whether neuroticism really affects only CES, and not the slave systems. Because PL might be influenced slightly, I chose the VSSP. The hypothesis to be tested was that high neurotics will have worse performance than low neurotics in the processing of cognitive tasks associated with the CES functions.

In chapter 3, in contrast to the Cantab tasks, I use the PRP dual-task paradigm including single tasks and dual tasks (includes fixed and random conditions), which can be made more complex by manipulating the SOA and through parametric manipulation (random task) compared to single tasks. The chapter aims to explore neuroticism-related differences in the PRP-paradigm. The hypothesis to be tested is that individuals with high scores on the neuroticism scale of the EPQ will have poorer performance compared to individuals with lower scores on neuroticism in the dual task experiment.

In Chapter 4, the stimuli are consisted of circles (visual stimuli) and beep tones (auditory stimuli). The previous dual task study (chapter 3) included faces and syllables. The stimuli in chapter 3 as such were rather neutral. However, because they were “social” (faces and syllables) they may have had an emotional/social component for some of the participants. Therefore, I aim to replicate the results of chapter 3. Based on this, I have designed a new experiment that includes non-emotional stimuli. Therefore I have replaced the male and female faces with yellow and blue circles; syllables to beeps. The hypothesis to be tested is whether high neurotics will have higher dual tasks costs in dual task processing, similar to my previous results.

In Chapter 5, I aim to investigate the effect of the load placed on the central executive system by increasing the number of S-R mappings in high and low neurotics during the cognitive dual task processing. Also, I aim to test whether the dual task cost occurs due to increased demands specifically on the CES, or whether there is any other kind of difficult situation that may cause this cost during the processing of the dual task. Finally, I use a questionnaire to investigate the perceived stress level in high and low neurotics. The hypothesis to be tested is whether high neurotics will have higher dual task cost compared with low neurotics, as the load increases during processing of the dual tasks; however, when the tasks become difficult for both groups the cost differences will be constant.

In Chapter 6, it is known that neuroticism impairs cognitive performance mostly in difficult tasks, but not so much in easier tasks. However, the functional neuroanatomical correlates of these performance impairments are unknown. I asked, “what are the neural correlates of neuroticism related differences in the PRP dual task paradigm?” To test this, I assessed brain activity by means of functional magnetic resonance imaging (fMRI) in low and high neurotics while they were performing a demanding dual-task and the less demanding component tasks as single-tasks.

In Chapter 7, I assess the findings of the empirical chapters and interpret their results. Furthermore, I indicate the importance of the study and directions for future research.

2 Chapter - Neuroticism related differences during processing of standard working memory tasks

2.1 Introduction

The first experiment was designed to explore the cognitive correlates of neuroticism by relating differences in scores across a group to neuropsychological tasks. Eysenck (1967) suggested that high neurotics perform worse on difficult tasks compared with low neurotics. ACT suggests more specifically that the detrimental effect of neuroticism mainly impairs three CES functions (switching, inhibition and updating) (M. W. Eysenck et al., 2007). Empirical studies have found evidence that neuroticism negatively influences WM task processing such as in dual tasks (see section 1.5.1) (Corr, 2003; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). Although these studies are informative, they did not specifically split the WM components in relation to the effect of neuroticism. In other words, the effects of neuroticism on standard WM tasks could reflect its effects on slave systems and specific CES functions (i.e. switching, inhibition, updating) (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). Thus, one needs to understand exactly whether neuroticism has a detrimental effect on the CES or the slave systems as well.

Miyake et al. (2000) specified the main functions of the CES (switching, inhibition and updating) by using a few standard WM tests (see section 1.3.2). A few studies have investigated the effect of anxiety on specific components of WM using dual task experiments (M. W. Eysenck et al., 2005). However, in this chapter, I investigate the effect of neuroticism upon single standard WM tasks using the EPQ scale (Eysenck, 1975) as a relatively direct measure of neuroticism. Because ACT suggests that the detrimental effect of neuroticism is generally associated with these CES functions, I select similar tests to Miyake et al. (2000) (i.e. tests similar to the Wisconsin card sorting test (WCST) and Tower of Hanoi (TOH)). I select a SWM task as well because I want to test whether neuroticism specifically affects the CES only, and not the slave systems. As PL might be influenced slightly (M. W. Eysenck et al., 2007), I have chosen the task associated with VSSP. Therefore, this study aims to not only replicate previous findings but also provide a new insight into the effect of neuroticism on components of WM. As the tasks that I have selected are similar to the WCST, TOH, and Corsi Block, I will briefly outline the findings for these tests in relation to the CES functions to clarify the rationale for this study.

The IED set shifting task is a computerized version of the WCST (Grant & Berg, 1948; Ozonoff et al., 2004). This type of task is considered to be the gold standard in terms of measuring the executive system (Baddeley, 1996a; Gamboz, Borella, & Brandimonte, 2009). These tasks are believed to measure the switching and inhibition functions of CES (Baddeley, 1996a; Goldberg & Gold, 1995; Shallice, 1982; Stratta et al., 1997). The IED set shifting task consists of coloured shapes (figures) and white lines (Ozonoff et al., 2004). The participant responds to one stimulus set (shape or lines) and learns from feedback which particular stimulus within that set they should respond to (Dickinson, Potter, Hybels, McQuoid, & Steffens, 2011; Ozonoff et al., 2004). After several trials a shift in the rules determining the feedback occurs (Dickinson et al., 2011; Ozonoff et al., 2004). There are two possible types of set shift in the task: intra-dimensional and extra-dimensional (Dickinson et al., 2011). An intra dimensional shift occurs when participants are required to switch from one exemplar to another within the same cognitive set, e.g. responding to a different shape within the shape set (Baddeley, 1996a; Dickinson et al., 2011). In an extra-dimensional shift the participant has to respond to the other stimulus set, e.g. lines instead of shapes (Ozonoff et al., 2004). The extra-dimensional shift is associated with conceptual flexibility, which means the ability to switch from one concept or cognitive set to another (Dickinson et al., 2011). It has been suggested that this task is strongly associated with the switching and inhibition functions (Friedman & Miyake, 2004; Miyake et al., 2000; Mullane & Corkum, 2007). Relying on this information, ACT suggests that if the task involves the switching and inhibition functions there will be a detrimental effect of neuroticism (Derakshan & Eysenck, 2009). Therefore, I hypothesize that high neurotics will perform worse than low neurotics on IED set shifting tasks.

The SOC task is a computerized version of tower tasks such as the tower of London and tower of Hanoi (Ozonoff et al., 2004). In this task, participants are presented with two displays (on the top and bottom of the screen), each with three colours distributed across three columns (Ozonoff et al., 2004). Participants are required to copy the configuration in the upper display by moving the balls in the lower display to match the configuration (Ozonoff et al., 2004). Participants are required to complete the task with the minimum number of moves (either 2 moves or 5 moves) indicated on the screen (Ozonoff et al., 2004). The task becomes more complicated and difficult as the minimum number of moves increases (Ozonoff et al., 2004). Miyake, et al. (2000) suggest that tower tasks may be associated with the inhibition function because participants use a perceptual strategy, ‘which involves simply making a next move that will bring the current state perceptually closer to the goal state'. Thus, Miyake et al. (2000) suggest that most people use a perceptual strategy for the tower of Hanoi (TOH) task and this strategy makes the task less demanding. Therefore, they suppose that tower tasks (including SOC tasks) should be taken as a measure of inhibition function (Miyake et al., 2000). If the task becomes highly demanding then it is more likely to be associates with the planning (the evaluation and selection of a sequence of thoughts and actions to achieve a desired goal) function of the central executive system (Miyake et al., 2000). However, there are differences between the tower of Hanoi and SOC task that may indicate that the SOC is a measure of the pure planning function (Ozonoff et al., 2004). For example, the TOH consists of a set of discs lined up like a pyramid. Participants are asked to copy a given specific configuration of the discs (Miyake et al., 2000; Ozonoff et al., 2004). Participants can only move one disc each time and they are not allowed to place a disc above a smaller one (Miyake et al., 2000; Ozonoff et al., 2004). The task requires a perfect minimum move solution (Ozonoff et al., 2004). Therefore, in contrast to the SOC, the TOH includes not only the planning function but also rule following and procedural learning, whereas the SOC involves a purer measure of the planning function of the CES (Ozonoff et al., 2004). Taken together, both inhibition and planning are functions of the central executive system and thus impairment during the processing of the SOC task can be interpreted as the task involving the central executive system (M. W. Eysenck & Calvo, 1992). Although such an interpretation would be applicable in terms of PET (Eysenck & Calvo, 1992), ACT specifically indicates that if the task involves the three main functions such as inhibition then anxiety impairs the task processing (M. W. Eysenck et al., 2007). In this view, it is important to explain the differences between similar tasks. Because the assumption of ACT regarding the inhibition function is based on the findings of Miyake et al., (2000), who used tower tasks to contribute to their findings, I suppose that the SOC task is associated with the inhibition function to some extent in addition to the planning function. Thus, I hypothesize that high neurotics will perform worse as the task difficulty increases compared to low neurotics.

Finally, the spatial working memory task (SWM) is a type of searching task. Participants are required to search for the tokens that are hidden in the boxes. They are required to remember each box they visit so that they do not search in the visited boxes again (Steele, Minshew, Luna, & Sweeney, 2007). The task demand increases as the number of boxes increases from 4 to 6 and then 8 and thus participants are required to maintain more locations of the boxes as the task demand increases (Steele et al., 2007). This task is a popular measure of visuospatial recall (Vandierendonck, Kemps, Fastame, & Szmalec, 2004). While it is strongly associated with the visuospatial sketchpad, it is associated less with the central executive system (Vandierendonck et al., 2004). According to ACT, WM storage systems (specifically the visuospatial sketchpad) do not suffer from a processing impairment in relation to neuroticism (M. W. Eysenck et al., 2007).

Taken together, the following tasks were selected for the study: IED set shifting tasks, SOC, and SWM. To that end, I compared high and low neurotics regarding their performance in the cognitive processing of these tasks.

The hypotheses to be tested are as follows:

I. High and low neurotics do not differ on the SWM task processing because SWM is associated with VSSP.

II. High neurotics have higher impairments in terms of processing SOC tasks because they are associated with the inhibition function.

III. High neurotics have greater impairments in IED set shifting tasks as compared to low neurotics because IED set shifting tasks are associated with the switching and inhibition functions.

2.2 Methods

2.2.1 Participants

To create extreme groups of high and low neurotics (High-N and Low-N, respectively), I screened participants using the 24-item neuroticism scale of the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975). Five participants were excluded because of current or previous depression or anxiety disorders according to the history of past or current psychiatric or neurologic disorders questionnaire. From the people screened using the neuroticism scale of EPQ, 45 people was selected to take part in the final experiment: 24 (12 female) were in the High-N group (mean EPQ score=18.10, range=16–24) and 21 (8 female) were in the Low-N group (mean EPQ score= 3.52, range=1–6). The two groups were roughly matched for age (High-N = 21.21 and Low-N=22.86) and gender (HN: 50% female, LN: = 40%). All of the participants were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971) and had normal or corrected to normal vision. Before participation each participant gave written informed consent. The participants were paid £10 for participating for one hour. The study was approved by the Department of Life Sciences ethics committee at Brunel University.

2.2.2 Materials

2.2.2.1 Ishihara colour-blindness test (Ishihara, 1987)

This test used six plates from which the participants had to distinguish coloured numerals presented on a background of an alternative colour; the last plate had no numeral printed on it (see Appendix C). The response had to be given within three seconds. This test was administered to ensure that any effects found using the CANTAB were not due to a vision deficiency.

2.2.2.2 Additional materials

A medical questionnaire and alcohol and caffeine consumption survey were also used; copies can be found in Appendices A and B respectively.

2.2.2.3 Beck Depression Inventory (BDI) (Beck, Epstein, Brown, & Steer, 1988)

The BDI is a 21-item self-report inventory validated for measuring the severity of depression (Beck, Steer & Garbin, 1988) and for detecting possible depression in healthy populations. Scores range from 0 – 63 and a score of 15 or over indicates possible depression. The inventory is composed of items relating to symptoms of depression such as feelings of guilt, hopelessness and irritability and physical symptoms such as fatigue (DSM IV-TR, 2000). The BDI's validity is well-established with samples from different populations and it has yielded adequate reliability estimates, with a mean coefficient alpha of 0.81 for non-psychiatric subjects (Beck, Steer, Ball & Ranieri, 1996).

2.2.2.4 EPQ (Eysenck Personality Questionnaire) (H. J. Eysenck & Eysenck, 1975)

The Eysenck personality questionnaire (EPQ) (see Appendix D) consists of three personality dimensions and a lie scale. Psychoticism includes 25, extraversion 21 and neuroticism 24. Neuroticism is characterized by a high level of negative affect such as depression and anxiety (see section 1.2.2). Scoring over 10 is an indication of neuroticism symptoms (see Eysenck, 1991). However, because I investigate high and low neuroticism, I focused on extreme samples of high and low neuroticism. Based on previous studies, participants were selected who scored over 15 (high neuroticism) and below 6 (low neuroticism) on the scale (Chan, Harmer and Goodwin, 2008; Chan, Goodwin and Harmer, 2007; Portello, Harmer, Flint, Cowen, and Goodwin, 2005).

2.2.3 Cognitive Stimuli: Cambridge Neuropsychological Tasks Automated Battery (CANTAB)

The current study includes three CANTAB tasks, which were: (a) Stocking of Cambridge (SOC), (b) Spatial Working Memory task (SWM); (c) Intra-Extra Dimensional Shift task (IED). The administered tasks are described briefly below.

2.2.3.1 Stocking of Cambridge (SOC)

The SOC is designed as a spatial planning task that is also suggested to be associated with the inhibition function. In this task, two displays are presented on a screen, one located at the top and the other located at the bottom. Each display contains three coloured balls. The participants are required to look at the top pattern (configuration) and copy that pattern in the bottom pattern by moving the coloured balls to their proper location on the touch screen (make the bottom pattern same as the top pattern) (see figure 2.1.). The participants touch the required balls and then touch the position of where the ball should be moved. Copying the top pattern is restricted by limited moves. Therefore, the number of moves indicates the task difficulty. The easiest condition is copying the pattern with one move. Thus, the task difficulty increases from one move to five moves, which is the most difficult condition. The time spent completing the task and the number of moves used is the results measures. There are four outcome measures (dependent variables). The initial move refers to the first move RTs that is successful for each pattern. Subsequent moves refer to successful moves RTs that were made after the first move for each pattern. The mean moves refer to the mean of the total successful moves in a task set (i.e mean of moves in 2 move SOC task). The minimum SOC moves refer to the total number of successful moves in the task (Ozonoff et al., 2004).

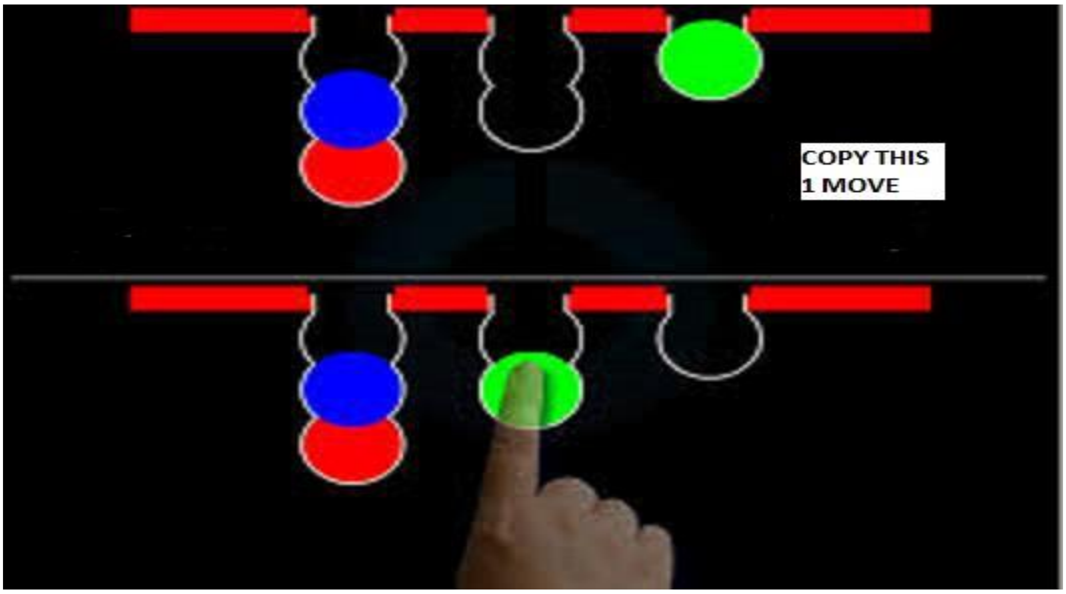

Figure 2-1 shows an example of the SOC task with one move. The top pattern must be copied in the bottom pattern. Thus, the participant moves the green ball into the empty location on the right

2.2.3.2 Spatial/visual Working Memory Task (SWM)

A Spatial Working Memory Task (SWM) is a self-ordered searching task. Subjects are asked to find hidden tokens in a spatial array of coloured boxes on the screen (see figure 2.2.). Subjects are informed that visited boxes that contain a token will not hold a token again in the same trial and thus they should seek another token which is previously not emptied boxes. Once they find a token they must place it in the column to the right of the screen. In this task, no feedback is given. The difficulty of the task is manipulated by increasing the number of boxes. Firstly, tokens are hidden in four boxes and subsequently the number of boxes is increased to six and then eight. The task assesses the accuracy of spatial/visual working memory with the following outcome measures: 'Within-search errors' (the number of times a participant revisits a box already found to be empty during the same search); 'between errors' (the number of times a participant revisits a box in which a token has already been found within a given trial); and total errors (total number of errors during the whole task) (Owen, Downes, Sahakian, Polkey & Robbins, 1990).

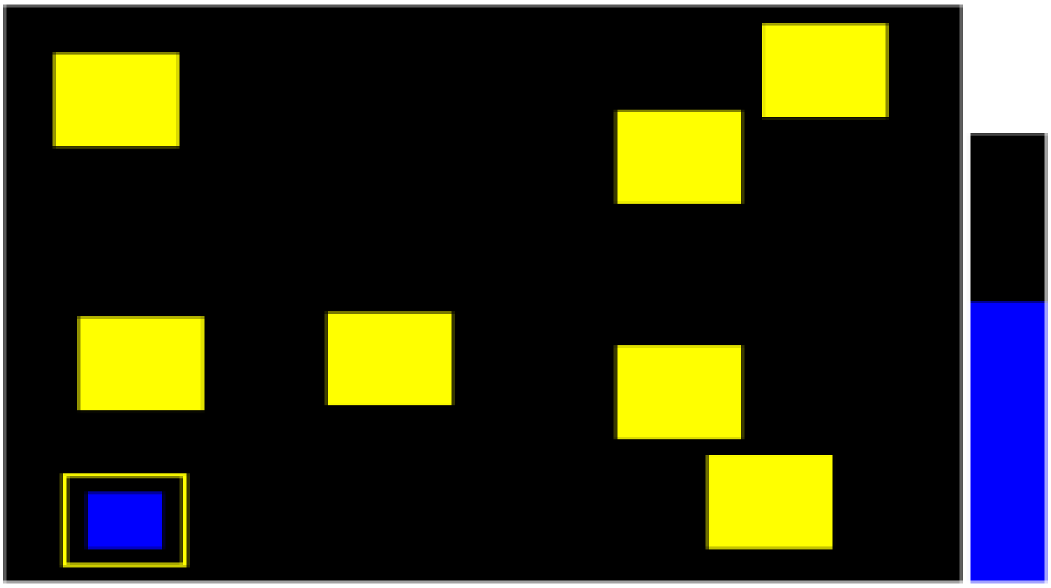

Figure 2-2 an example of an SWM task with 8 boxes. Blue token in the left bottom is the target. Participants look for blow tokens by touching yellow tokens.

2.2.3.3 Intra-Extra Dimensional Shift Task (IED)

IED is an attentional set shifting task that is a computerized analogue of the Wisconsin card sorting test (Grant & Berg, 1948). This task measures the participants' ability in terms of rule acquisition and switching, which is associated with flexibility of attention. The task consists of nine stages and each stage has a maximum of 50 trials. There are two stimuli: one is colour-filled shapes and the other is white lines in a display (see figure 2.3). While a simple stimulus is only consists of one dimension, either a shape or a line (i.e. panel A), a compound stimulus includes both dimensions, shapes and lines (i.e. panel B) (Ozonoff et al., 2004).

In the task, there are two rules. The first rule is called an intra-extra dimensional shift and participants should respond to shapes while ignoring lines. The second rule is an extra-intra dimensional shift; therefore, they should respond to lines while ignoring shapes. When the experiment started, the participants were required to touch the patterns to learn which rule they should follow. For example, if the shifts are intra-extra dimensional, then the relevant dimension is shapes and participants should respond to shape discrimination. If the shifts are extra-intra dimensional they should respond to line discrimination. When participants follow a rule, it changes after six correct responses and then the other rule starts. In this case, participants were required to switch the rule and respond to the task based on the new rule. Feedback was given after each response and thus the participants could learn the correct responses and after six correct responses a new compound stimulus was displayed, still varying along the same two dimensions, shape and line. The feedback for correct responses was a high auditory tune in the colour green, whereas a low auditory tune was given for incorrect responses in the colour red, simultaneously with the participant's response (Ozonoff et al., 2004).

The task has four outcome measures. It assesses errors, and the numbers of trials and stages completed. Mainly, the primary outcome measures are "stages completed", which refers to successfully completing one of the tasks set (i.e. making 6 correct responses either in the intra-dimensional or extra-dimensional section) (total number of stages completed successfully); "EDS errors" (errors made at the stage where the participant is required to make an extra-dimensional shift); "total errors (adjusted)" (aggregate number of errors made in the task across all stages attempted, adjusted by adding 25 for each stage not attempted due to premature failure); and "total trials (adjusted)" (total number of trials completed in all stages attempted, adjusted by adding 50 for each stage not attempted due to premature failure) (Ozonoff et al., 2004).

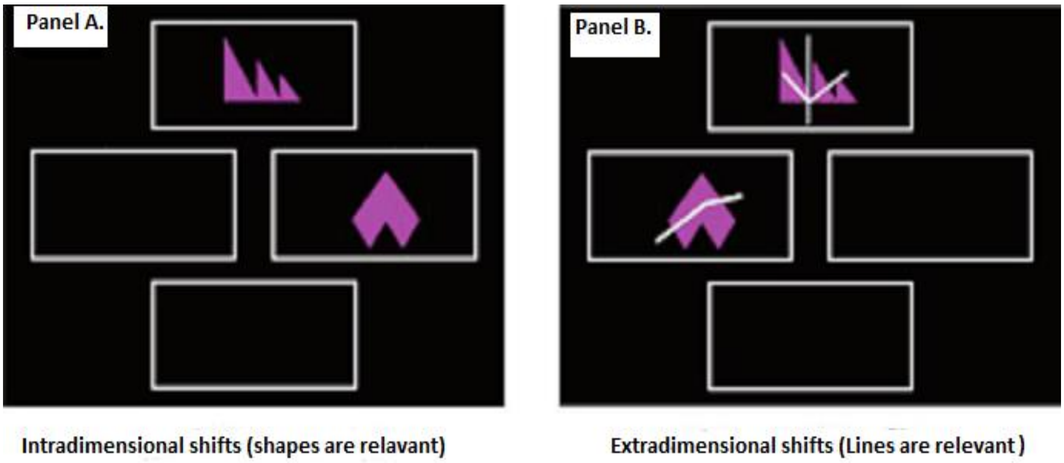

Figure 2-3 shows an example of the IED set shifting task Panel A. shows an easy condition of the intra-dimensional task. Panel B. shows a condition of the extra-dimensional task.

2.2.4 Procedure

All of the participants were given time to read and sign their written informed consent forms (see Appendix E for consent form) and were tested individually in a cubicle room. First, the participants were given a medical questionnaire and a caffeine consumption survey, an

Ishara colour test and a BDI. Based on the questions, I employed the following exclusion criteria: presence of any past or current major medical, neurological or psychiatric illness that might have diminished cognitive functioning; use of psychoactive medication; consumption of alcohol; consumption of ≥8 cups or ≥ 900mg caffeine; scoring over 15 in the Beck depression inventory (BDI) (Beck et al., 1988); and colour blindness (Ishihara, 1987). Thus, eligible participants were selected. The participants were given the EPQ and were informed how to complete the questionnaire. Later, the participants were seated in front of the CANTAB computer, which is an Advantech personal computer (Model PP-120-RT) with a 10 ½ in. touch-screen monitor. The SOC, SWM and IED tasks were presented to the participants in a counterbalanced order.

The CANTAB tasks started with the practice session to introduce the participants to the touch screen and eliminate sensorimotor or comprehension difficulties that might restrict collecting valid data from the participants. After the participants had completed practice task, they continued to the three main tasks, the SOC, IED and SWM. The participants were instructed verbally from the script and some tasks were demonstrated by the experimenter. When the participants were not clear how to proceed, appropriate instructions were given. To eliminate order effect, the CANTAB tasks were counterbalanced. Finally, on completion of all of the tasks, a debriefing form was issued.

2.3 Data analysis

If not otherwise noted, in the following analyses, an analysis independent t test was used. The significance for all effects was reported at $p < .05$ (two tailed) unless otherwise stated. The grouping variable was EPQ- Neuroticism with the levels high and low neuroticism. The testing variables were the task conditions. . See Table 2.1 for a summary of the outcome measures for the individual CANTAB tasks. In all independent t test analysis Levene's test for equality of variances were considered. It should be noted that Levene's test for equality of variances are reported when it is significant, otherwise, when it is not significant, the results were reported with normal independent t test results. Therefore, in the current chapter, because Levene's test for equality of variances were not significant, the results reported with independent t tests results only.

Cognitive task	Measures/DVs
Spatial Working Memory (SWM)	Within errors Between errors Strategy
Intra-Extra Dimensional Shift (IED)	EDS errors IED Stages completed IED Total errors (adjusted) IED Total trials (adjusted)
Stocking of Cambridge (SOC)	Initial 2, 3, 4, and 5 moves Mean 2, 3, 4, and 5 moves Subsequent 2, 3, 4, 5 moves SOC Min. Moves

Table 2-1 Shows outcome measures of (Dependent Variables (DV)) cognitive tasks

2.4 Results

I calculated independent t test for each outcome measure in each task with neuroticism as a between group factor factors. The IED set shifting task (which associates with switching and inhibition function for testing hypothesis III) variables demonstrated that high neurotics significantly differed from low neurotics in the processing of the IED set shifting task. The high neurotics made more errors than the low neurotics during the processing of the extra-dimensional set shifting; [EDS errors, $t(45) = 9.25$; $p < .01$]. Furthermore, the high neurotics had a higher total number of errors across the tasks, i.e. the high neurotics always made more errors than the low neurotics [total errors, $t(45) = 8.40$; $p < .01$]. The high neurotics performed considerably higher numbers of trials to achieve the tasks compared to the low neurotics [total trials (adjusted), t (45) = 8.93; p < .01]). Additionally, the numbers of successfully completed tasks were higher among the low neurotics compared to the high neurotics [stages completed main effect, t (45) = 7.36; p < .01]) (see table 2.2). Taken together, these results indicate that, although the high neurotics took more trials to achieve a task, they still had more errors and a lower number of successfully completed tasks.

Group Statistics					
	Groups	No	Mean	SD	Std. Error Mean
EDS errors	HIGH N	24	10.38	10.16	2.07
	LOW N	21	3.52	4.34	.94
IED stages completed	HIGH N	24	8.54	.83	.17
	LOW N	21	9.00	.00	.00
IED total errors	HIGH N	24	18.38	11.45	2.33
	LOW N	21	10.76	5.66	1.23
IED total errors adjusted	HIGH N	24	23.58	19.83	4.04
	LOW N	21	10.76	5.66	1.23
IED total trials	HIGH N	24	81.88	18.18	3.71
	LOW N	21	69.71	13.85	3.02

Table 2-2 Number of errors and successfully completed stages for participants with high levels of neuroticism (High-N,) and low levels of neuroticism (Low-N).

Tabular from in table 2-2 is also presented in the form of boxplot graphs to assist clearly see mean and standard deviations in high and low neurotic groups.

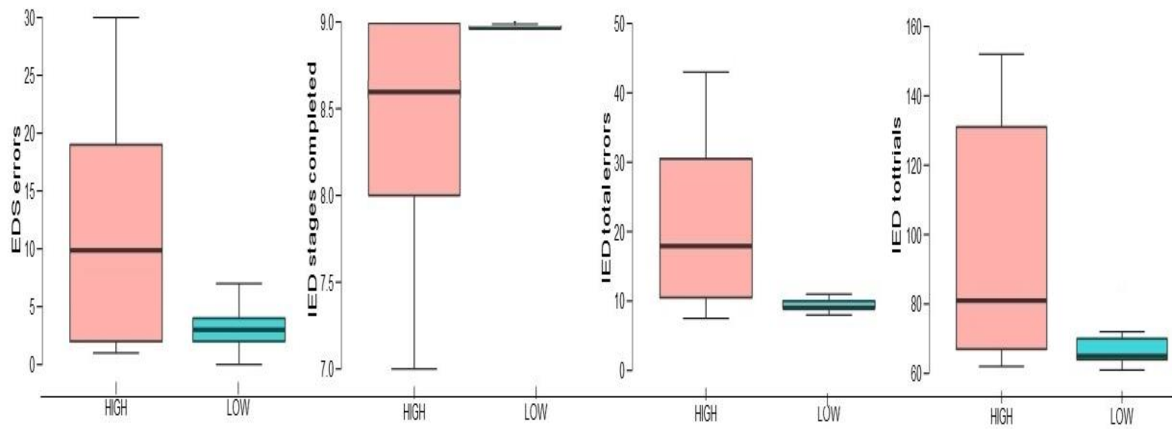

Figure 2-4 shows mean and SD distribution in the form of boxplot for participants with high levels of neuroticism (High-N, pink box) and low levels of neuroticism (Low-N, yellow box) through IED set shifting task variables. Note that different scales have been used for each variable.

Regarding the SOC tasks (which strongly associates with planning function and weakly associates with inhibition function for testing hypothesis II.), the independent t test results demonstrated that the high and low neurotics did not differ with regard to either the number of moves or the total time for task completion p>.05 (see table 2.3.). All pairwise comparisons were non-significant for RTs: [all t (45) < (largest: 3.50/ lowest: .10), all p > (largest: .10/ lowest .93)] and for number of moves: [all t (45) < (largest: 3.50/ lowest: .10), all p > (largest: .10/ lowest: .93)]. However, generally, based on the mean values, the high neurotics were numerically faster, with a higher mean number of moves, and less accurate than the low neurotics. These results may indicate that the high neurotics used a compensatory strategy (speed-accuracy trade off) to achieve the task faster while ignoring error execution. Taken together, all of the variants showed that both the high and low neurotics performed the SOC tasks from the easy version (two moves) to the difficult version (5 moves) and they did not differ statistically (p> .05) either in terms of RTs or accuracy (number of moves that they attempted to achieve the tasks). However, despite the non-significant results regarding the SOC tasks, numerically, the high neurotics had faster reaction times with lower accuracy.

Group Statistics					
	Groups	No	Mean	SD	Std. Error Mean
SOC Initial 2move	HIGH N	24	1305.81	887.45	181.15
	LOW N	21	1574.15	1018.39	227.72
SOC Initial 3move	HIGH N	24	3811.62	2466.57	503.48
	LOW N	21	3730.75	3020.33	675.36
SOC Initial 4move	HIGH N	24	6484.83	3837.66	783.36
	LOW N	21	9179.95	7271.48	1625.95
SOC Initial 5move	HIGH N	24	8907.95	6731.68	1374.10
	LOW N	21	13530.50	9233.17	2064.60
SOC Mean 2move	HIGH N	24	2.08	.28	.05
	LOW N	21	2.05	.22	.05
SOC Mean 3move	HIGH N	24	3.12	.33	.06
	LOW N	21	3.07	.18	.04
SOC Mean 4move	HIGH N	24	5.21	.98	.20
	LOW N	21	4.95	.55	.12
SOC Mean 5move	HIGH N	24	6.56	1.73	.35
	LOW N	21	5.98	1.15	.25
SOC Subsequent 2move	HIGH N	24	133.25	216.25	44.143
	LOW N	21	117.10	209.77	46.90
SOC Subsequent 3move	HIGH N	24	145.32	328.04	66.96

	LOW N	21	250.25	474.54	106.110
SOC Subsequent 4move	HIGH N	24	1188.25	1658.76	338.59
	LOW N	21	1204.53	1485.13	332.08
SOC Subsequent 5move	HIGH N	24	500.51	585.33	119.48
	LOW N	21	747.28	989.71	221.30
SOC Min. Moves	HIGH N	24	9.20	2.28	.46
	LOW N	21	10.00	1.41	.31

Table 2-3 Response times (initial and subsequent moves) and number of moves (mean moves) for participants with high levels of neuroticism (High-N,) and low levels of neuroticism (Low-N).

Similarly, to test effect of neuroticism on visuospatial sketchpad (hypothesis I), in dependent t test used to analyse results of SWM tasks. The results show no differences were found regarding any variables of SWM p> .05 between groups. Thus, all of the comparisons were non-significant. (all t (45) < (.05), all p >.47) (see table 2.4). These results indicate that the high and low neurotics performed similarly on the spatial working memory tasks from the easy to the difficult versions.

Group Statistics					
	Groups	No	Mean	SD	Std. Error Mean
SWM between errors	HIGH N	24	16.83	12.30	2.51
	LOW N	21	16.62	17.60	3.84
SWM tot. errors	HIGH N	24	18.29	12.58	2.57
	LOW N	21	17.00	17.91	3.90
SWM within errors	HIGH N	24	1.17	2.03	.41
	LOW N	21	.90	1.26	.27

Table 2-4 shows the error rates and searching strategy for participants with high levels of neuroticism (High-N,) and low levels of neuroticism (Low-N).

2.5 Discussion

The results show that the high neurotics had a greater impairment than the low neurotics during the IED set shifting task processing. Despite the higher number of trials they had higher errors when they made an extra-dimensional shift and also across the entire task (total errors). The high and low neurotics did not differ statistically on the SOC task processing regarding either RTs or accuracy. However, numerically, the high neurotics were faster with lower accuracy. Finally, the high and low neurotics did not differ on the SWM task processing because they had similar accuracy across all conditions.

Eysenck (1967) suggests that high neurotics perform difficult tasks worse than low neurotics. Furthermore, ACT suggests a more specified assumption that high neuroticism impairs certain functions of the CES (switching, inhibition and updating) but not the storage systems. The results demonstrate that the assumption of Eysenck, (1967) cannot be generalized regarding task difficulty for SWM and partially for SOC, because despite the increasing task demand in these tasks, the high and low neurotics did not differ in terms of their performance. Based on the inverted U curve, Eysenck (1967) suggests that if the task is very easy or very difficult, high and low neurotics may perform similarly. The reason for that is that if the task is easy the arousal level may not reach the threshold level even in high neurotics. If the task is very difficult, then the arousal level may exceed the threshold in both high and low neurotics. Thus, in both cases, high and low neurotics may perform similarly in the task processing. For instance, if an arbitrary scale of task difficulty ranges from 0 (very easy) to 10 (very difficult), as soon as a task is more difficult than level from 5 to 8, high and low neurotics differ in their performance. Below 5, high and low neurotics are the same, because the task difficulty is not high enough to differentiate them.

This interpretation might account for the results of the SOC task but not those of the SWM task. It has been suggested that normal subjects perform easily in the SWM two and four box tasks. However, they suffer due to task difficulty when searching 5 or 6 boxes on the screen (Steele et al., 2007; Vandierendonck et al., 2004). In the current study, the SWM task is started by searching from 2 boxes to 8 boxes. In other words, in the SWM task, the demand increased by searching tokens from 2 to 4; 4 to 6 and 6 to 8 boxes. Thus, the participants had to maintain more box locations as the demand increased (Steele et al., 2007; Vandierendonck et al., 2004). Therefore, it seems that the task difficulty was well manipulated. This task is more likely to be associated with the visuospatial storage of working memory (Baddeley, 1996a; Vandierendonck et al., 2004). Furthermore, this finding is supported by theories such as ACT (M. W. Eysenck et al., 2007) and PET (M. W. Eysenck & Calvo, 1992) because these theories suggest that if a task is associated with VSSP then high neurotics perform the same as low neurotics.

The interpretation of task difficulty may be approachable for SOC tasks for two reasons. First, numerically, the high neurotics were faster but less successful on task completion. The high neurotics may have narrowed their attention for faster task processing and they may neglect the error execution in the task (speed-accuracy trade-off) (Easterbrook, 1959). It is known that higher error rates are related to an impairment of the inhibition function, because avoiding errors requires inhibiting the proponent task until the necessary task has been executed (Carter et al., 2000; MacDonald et al., 2000). Second, SOC task processing is associated with the inhibition function (Miyake et al., 2000; but see Oznonoff et al, 2004), and furthermore ACT (M. W. Eysenck et al., 2007) suggests that high neuroticism impairs task processing if the task is associated with inhibition. Considering these two points regarding the SOC, because the task was not optimally difficult, the arousal level may not have exceeded the activation threshold in the high neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967) and thus both the high and low neurotics had a statistically similar performance. Another potential reason is that the SOC may not be strongly associated with the inhibition function but rather the planning function as the load increases (Ozonoff et al., 2004). Therefore, neuroticism did not impair the task processing because the increased task demand was associated with planning and not with inhibition (Ozonoff et al., 2004). Miyake et al. (2000) suggest that the TOH task processing is associated with inhibition. However, the TOH seems to be more demanding than the SOC regarding the inhibition function because the TOH includes more rules and procedures compared to the SOC (Ozonoff et al., 2004). For instance, the TOH and SOC require copying a pattern with a certain number of moves (Ozonoff et al., 2004). In addition, the TOH is a pyramidal shape and thus it requires copying the pattern by selecting a disc which has the proper size. (i.e. a big size disc cannot be placed on a small disc for completion of the pyramid) (Ozonoff et al., 2004). Taken together, the results are more likely to be in line with ACT (M. W. Eysenck et al., 2007), which suggests that the CES functions (switching, inhibition and updating) are influenced by the detrimental effect of neuroticism. It is also indicated that high and low neurotics do not differ either in their reaction times or task accuracy in the processing of visual repository (H. J. Eysenck, 1967).

It has been suggested that high levels of neuroticism will cause impairment in processing efficiency and performance effectiveness during the processing of tasks, if they involve the switching and inhibition functions (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). Considering this assumption, I hypothesized that high neurotics will differ considerably in favour of low neurotics during the processing of IED set shifting tasks. The results obviously demonstrate that the high neurotics made more errors both in the extra-dimensional shifts (EDS errors) and across all of the tasks. Also, they performed a greater number of trials to learn the tasks than the low neurotics, and they successfully completed less number of stages. As mentioned, the IED set shifting task has been used as a measure of executive functions (Delis, Kaplan, & Kramer, 2001; Gamboz, et al., 2009 but see Stratta, et al., 1997). It has been suggested that this task is strongly associated with the switching (Miyake et al., 2000) and inhibition functions (Mullane & Corkum, 2007). Therefore, the higher error rates made by high neurotics indicate that a high level of neuroticism impairs task processing that involves not only the switching but also the inhibition function of the central executive system (Eysenck et al, 2007). For example, in the IED set shifting task, the participants were required to switch their attention from one rule to another (Ozonoff et al., 2004). Likewise, they had to switch their attention from the inter-dimensional stage to the extra-dimensional stage (Ozonoff et al., 2004). To do that, they were also required to inhibit previous task relevant information, which had become task irrelevant information (Baddeley, 1996a; Mullane & Corkum, 2007; Ozonoff et al., 2004). Therefore, the high neurotics may not have been able to successfully switch the focus of their attention from one dimension to another and inhibit irrelevant responses and thus they made more errors. Relying on this knowledge, my hypothesis confirms reports of attentional control theory, which states that the detrimental effect of neuroticism is associated with the switching and inhibition functions of the CES in the IED set shifting task.

Altogether, the present experiment results demonstrate that highly neurotic participants showed reduced performance when the task demand involved the CES in terms of switching and inhibition. On the other hand, if the task included demand in storage systems, the high neurotics performed similarly to the low neurotics. In the next study, the construction of the cognitive system in relation to neuroticism will be examined in regard to processing efficiency, and I will use the PRP dual task experimental paradigm. In the next study, I will test whether the current findings regarding the central executive system (i.e. switching, inhibition and updating) are specific to the aforementioned tasks or whether similar impairments can be found in dual task processing that involves the central executive system.

3 Chapter – Neuroticism related differences during processing of Dual task: Task order coordination

3.1 Introduction

ACT suggests that high neuroticism impairs task performance in demanding WM tasks, which are associated with the three CES functions, whereas it does not have a major influence on the storage systems (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). In line with that, the previous study (chapter 2) shows that high neurotics had higher task impairment when the task mainly demanded the switching and inhibition functions whereas high and low neurotics performed similarly on the VSSP task. Worry and higher arousal level are the most prominent features of high neurotic/trait anxiety individuals (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; M. W. Eysenck et al., 2007). Thus, worry increases the arousal level, which causes task irrelevant activities that interfere with attention during task processing (M. W. Eysenck & Derakshan, 2011). Because high neurotics use a reactive control mechanism (a bottom up process) their attention focuses on task irrelevant activities (Braver, 2012). Therefore, they cannot inhibit or suppress task irrelevant activities and switch their attention to task relevant activities (Braver, 2012; Derakshan & Eysenck, 2009).

Although I found that Eysenck’s (1967) assumption in relation to task difficulty could not be generalized for all of the tasks, I still consider one assumption regarding the arousal level threshold in high neurotics. The detrimental effect of neuroticism is only revealed when the arousal level exceeds the activation threshold (H. J. Eysenck, 1967). For that to be the case, a cognitive task has to be sufficiently demanding (H. J. Eysenck, 1967). For example, some researchers suppose that the SOC task is associated with the inhibition function but the results regarding the SOC tasks were non-significant in chapter 1. I conclude that one potential reason for that result is because the SOC task may not have been demanding enough in relation to the inhibition function (Corr, 2003; Flehmig et al., 2010). Therefore, a task should be demanding enough to investigate the detrimental effect of neuroticism (H. J. Eysenck, 1967).

Considering both the assumption of ACT (related to CES functions) (M. W. Eysenck et al., 2007) and the arousal based theory of neuroticism (H. J. Eysenck, 1967) (related to arousal threshold) together, a task should be associated with the CES functions and it should be demanding enough to arouse high neurotics during the task processing. According to Baddeley (1996, 1997), dual task experimental paradigms are one of the best ways to investigate the CES because in this way demand is placed on the CES functions (see section 1.3). Relying on this suggestion, a few studies have used a combination of two standard WM tasks as dual tasks to investigate anxiety related differences during task processing. Regarding this study, I found that the PRP dual task paradigm is more approachable than using a combination of two WM tasks because it allows for investigating task processing with various demand manipulations (i.e. a comparison of dual task (demand on CES) and single tasks (demand in non-CES task) (Szameitat et al., 2016). In other words, PRP dual task processing has been found to be strongly associated with the CES functions (switching, inhibition and updating) whereas single tasks are rather simple and do not require the CES (see section 1.3.3) (De Jong, 1995b; Luria & Meiran, 2003). Furthermore, it has been theoretically (Logan & Gordon, 2001; Pashler, 1994b) and empirically (De Jong, 1993; Marois & Ivanoff, 2005; Szameitat et al., 2016) well investigated.

In this study, I investigate the processing of two tasks by using different sensory modalities that draw upon distinct sections of WM storage, the phonological loop (auditory) and the visuospatial sketchpad (visual). The independence of the input and storage of information means that if there is a cost in performing them concurrently, it is likely to be due to the existence of a bottleneck at the response selection stage (Pashler, 1994b). The participants react to the visual and auditory stimuli respectively using their right and left hand fingers (Pashler, 1994b). It should be noted that using the two hands may actually not be perfect but it is a practical solution for task performance; the two hands are somewhat coupled and not fully independent of each other (Pashler, 1994b). That is why some studies have used manual-vocal output. However, this means that strictly speaking, interference could also arise from the output/motor stages (Pashler, 1994b).

Based on the knowledge given in the paragraphs above, this chapter consists of a dual task study that investigates whether interference in the PRP dual task paradigm produces greater performance costs in high neurotics compared to low neurotics. The PRP dual task paradigm is more cognitively demanding than performing tasks individually and specifically requires greater use of executive functions such as switching, inhibition and updating (De Jong, 1995b; Luria & Meiran, 2003; Szameitat et al., 2016). Thus, in this study, I manipulated the task demand in three ways. To this end, first, I compared the reaction times and error rates in single and dual tasks for high and low neurotics. Furthermore, I manipulated the task demand in the dual tasks through SOA manipulation (short and long SOA) and task order manipulation (fixed and random tasks).

In the first manipulation, I compared high and low neurotics regarding their performance in single and dual tasks. The single task requires one response and it is relatively simple. Because the single task is not demanding and requires so little in terms of central executive demand (Logan & Gordon, 2001; Pashler, 1993; Pashler, 1994b; Pashler et al., 2001), according to the arousal based theory of neuroticism (H. J. Eysenck, 1967), PET (M. W. Eysenck & Calvo, 1992) and ACT (M. W. Eysenck et al., 2007) high and low neurotics will not differ regarding their RTs and error execution. Earlier studies have indicated that high and low neurotics had similar RTs and error rates in single tasks (Szymura & Wodniecka, 2003). On the other hand, the dual task requires two responses and it is relatively demanding (Logan & Gordon, 2001; Pashler, 1993; Pashler, 1994b). As explained in the literature review section (see 1.5.2), there is a general consensus that the locus of the performance bottleneck in the PRP paradigm is at the response selection stage in the CES (Pashler, 1993; Pashler, 1994b). Therefore, while two tasks can be processed in parallel through the perceptual and motor response stages, only one task can be processed at a time in the bottleneck stage (Pashler, 1994b). When two tasks are performed simultaneously they compete during the bottleneck stage and thus the processing of the second task starts when the processing of the first task ends (Jiang, 2004; Szameitat et al., 2011). Although both tasks may be influenced, the bottleneck always causes a delay, particularly in the completion of task 2 (Pashler, 1994b). The use of the switching, inhibition and updating functions plays a pivotal role during bottleneck processing compared to single tasks (see section 1.3.3) (Luria & Meiran, 2003). Therefore, because the dual task is relatively demanding and the demand is mainly associated with the CES functions, high neurotics should have a higher impairment in the dual task processing compared to the low neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). I will use the term 'dual task combination costs' to assess the results in relation to the single and dual task processing in high and low neurotics. Therefore, to derive a dual task cost, I will subtract the single task RTs from the dual task second RTs (Szameitat et al., 2011). The hypothesis to be tested is, high and low neurotics have a similar performance in the single task because it is a non-CES task whereas high neurotics have a considerable task impairment compared with low neurotics in the dual task (dual task combination costs) because it demands the CES.

Secondly, in this study, the magnitude of the task demand increased along the task coordination by SOA (0 and 1000ms SOA) variations. Increasing task demand by the SOA manipulation may place a pure demand on the bottleneck that is linked to the CES because no additional stimuli are inserted. Thus, the demand increase is undertaken completely by SOA manipulation on the CES, which is associated with the preparatory process and bottleneck. When the SOA is short, higher stimuli competition in the bottleneck causes a delay in the processing of the second stimulus (Jiang, 2004; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2011). However, when the SOA is long there is more time for using the switching functions (Monsell, 2003) so the CES demand is lowered in this condition (Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2011). It has been suggested that if the SOA is short, the task demand is considerably higher compared to long SOA tasks (Luria & Meiran, 2003; Luria & Meiran, 2005) because there is no time given for preparation of the switching and inhibiting tasks. Therefore, when the SOA is short (0 ms.), task processing requires higher use of the CES functions compared to long SOA tasks (Luria & Meiran, 2003; Luria & Meiran, 2005). According to Monsell, (2003) inhibition is needed in the switching tasks. For example, in dual task processing switching is needed to shift the focus of the bottleneck from the first task to the second task and inhibition is also required to suppress the second task processing until the first task has been processed in the bottleneck (De Jong, 1995a; Logan & Gordon, 2001; Szameitat et al.,2016). Comparisons of second RTs for long and short SOAs indicates PRP effect which is evident by delay in processing of RT2 in short SOA task (Logan & Gordon, 2001; Pashler, 1994a). In other words, the PRP effect is derived by substation of RT2 short SOA from RT2 long SOA as evidence of a delay in bottleneck processing (Logan & Gordon, 2001; Pashler, 1994a). The CES functions for the switching, inhibition and updating of task related rules and context may encounter pressure due to the limited time during the bottleneck process (Luria & Meiran, 2005). A potential reason for that is the preparatory process occurring during dual task processing (see section 1.3.3) (De Jong, 1995b; Luria & Meiran, 2005; Szameitat et al., 2016). Generally, people are able to prepare an S-R mapping in a long SOA dual task (i.e. 1000 ms) (Monsell, 2003). However, when two tasks are presented in very rapid succession (or simultaneously such as 0 ms.) the response preparation process may cause an additional delay in the processing of the task, which is not present when the interval between the presentations of the two stimuli is increased (De Jong, 1995b; Logan & Gordon, 2001; Luria & Meiran, 2003). This additional delay will further exacerbate the dual task costs beyond those incurred by the central bottleneck stages (Logan & Gordon, 2001). Therefore, it follows that when two tasks are presented simultaneously (e.g. with SOA 0) a highest dual task cost will be observed due to maximizing the demand on the bottleneck and preparation limits (Logan & Gordon, 2001). Therefore, in this experimental design, in half of the dual task conditions, the two tasks were presented simultaneously, which is relatively demanding and stressful (Luria & Meiran, 2003). In the other half, the tasks were presented with a longer (1000 ms) SOA, which is relatively less demanding and stressful (Luria & Meiran, 2003). In this context, high neurotics have a greater dual task cost compared to low neurotics because the detrimental effect of neuroticism causes a greater processing time being expended on task irrelevant activities. In high neurotics, this increased dual task cost should be maximal for short SOAs and should be most pronounced in the RTs for the second task, which previous PRP studies have shown is more greatly affected (Logan & Gordon, 2001; Pashler, 1994a). In contrast, when the SOA is relatively long the dual task cost between high and low neurotics should be smaller than in short SOA, because there is additional time to prepare S-R mappings and processing in the bottleneck. Logan & Zbrodoff, (1982) suggest that the minimum required SOA for second task processing to be least affected would be between 400 and 600 ms in dual tasks. Therefore, it has been suggested that when SOA is set to 1000 ms. (as in the current study) then the two tasks can be processed with a much reduced overlap (Logan & Gordon, 2001; Pashler, 1994a). As a consequence, I hypothesize that the dual task cost differences between high and low neurotics will be higher in short SOA tasks than long SOA tasks because the longer SOA will minimize the detrimental effect of neuroticism during the preparatory process and bottleneck stage.

Finally, I manipulated the task demand specifically on the switching and inhibition functions. To support the conclusions drawn from comparing the STs to the DTs and the long and short SOAs, it is useful to complement the current experimental logic with a parametric manipulation on the dual-task specific demands on the switching and inhibition functions of the CES. As noted in the literature review (see sections 1.3.3 and 1.5.1), inserting additional stimuli may increase the load not only in the central executive system but also in the storage systems of working memory (Szameitat et al., 2002). One previously validated method of targeting central executive load is presenting dual tasks in a random order (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Stelzel et al., 2008a; Szameitat et al., 2002). The random order requires rearrangement of the S-R mappings as soon as the presentation order is altered and so the central executive load is increased without a contamination effect on other systems (Szameitat et al., 2002). These increased demands show as switch costs, i.e. prolonged RTs in switched trials (which the order of the current dual-task trial changed) as compared to repeated trials (the order is the same as in the previous trial) (Luria & Meiran, 2005). In detail, fixed order tasks are visual and then auditory (V-A) or auditory and then visual (A-V) and thus the task is always either V-A or A-V. I assessed whether the fixed dual task is associated with the CES functions (Szameitat et al., 2016). In the random condition, the CES demand increased more in terms of the switching and inhibition functions (De Jong, 1995b). In the random task, the tasks were presented randomly such as V-A, A-V, V-A, A-V, A-V, V-A. Therefore, sometimes the order was repeated (repeated orders), and sometimes the task order was switched (switched orders). The participants were required to use the switching and inhibition functions extensively because the task order presentation came unexpectedly and they had to rearrange the task related context and rules each time (see section 1.3.3) (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005). De Jong, (1995b) found that the demand on the switching and inhibition functions is higher in random tasks than in fixed dual tasks. Because in a fixed dual task the presentation of the task order does not change, the participants implement the same scheduling strategy during the task processing (De Jong, 1993; De Jong, 1995b). However, in a random condition, the participants have to rearrange the scheduling strategy whenever the presentation of the task order changes (De Jong, 1995b). Therefore, the task demand is higher in a random condition than in fixed order dual tasks because the requirement to frequently rearrange the task coordination places a higher demand on the switching and inhibition functions (De Jong, 1993; De Jong, 1995b). For example, in a random task one trial (i.e. A-V: auditory=>visual) they had to suppress the second task (visual task) until the first task (auditory task) had been processed, and then they had to inhibit a previous online task (auditory) and switch their focus of attention from the first task (auditory task) to the second task (visual task). In the next trial (i.e. V-A: visual => auditory), this arrangement was totally changed and thus the inhibition and switching functions had to be implemented in reverse (Luria & Meiran, 2005). De Jong (1995) suggests that task processing is automatically set in the bottleneck mechanism. There might be more than one switching in this condition (De Jong, 1993; De Jong, 1995b). When the first task comes, the second task is automatically set for processing in fixed task (De Jong, 1995b). However, in a random dual task, when the task order is switched the wrong task is set for processing because of that automaticity (De Jong, 1995b; Luria & Meiran, 2005). Therefore, this also has to be switched for the correct responses (De Jong, 1995b; Luria & Meiran, 2005). This switching is involved in inhibition of the wrong task as well (De Jong, 1993; Szameitat et al., 2016). Luria & Meiran, (2003) separated trials as repeated order and switched order trials in a random task. It has been suggested that comparison of repeated and switched trials allows for a strong insight into the relation between the roles of switching and inhibition (Luria & Meiran, 2003). Based on this information, to understand the role of the switching and inhibition functions, RTs in switched orders are compared with RTs in repeated orders. In the current study, I tested whether high and low neurotics differ in terms of the amount of switch costs by comparing repeated orders and switched orders in high and low neurotics, as ACT suggests that the detrimental effect of neuroticism mainly influences the switching and inhibition function of the CES during cognitive task processing (see section 1.4.5). Random tasks are known to be strongly associated with switching and inhibition (see sections 1.3.3). Therefore, I hypothesize that the switching cost will be higher in high neurotics compared with low neurotics.

In the current study I propose the following hypotheses:

I. High neurotics will show a greater PRP effect compared to low neurotics
II. High neurotics will show a higher dual task combination cost than low neurotics in the processing of dual tasks whereas no difference will be found between the groups in single tasks.
III. The dual task combination cost differences between high and low neurotics will be greater for short SOA than long SOA tasks.
IV. The switching cost will be higher in high neurotics compared to low neurotics in a random task (switched trials vs repeated trials).

3.2 Methods

3.2.1 Participants

To create extreme groups of high- and low-neurotics (High-N and Low-N, respectively), I screened 400 participants using the 24-item neuroticism scale of the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975). From those screened, 43 were selected and agreed to participate in the study. Three participants were excluded due to a self-reported history of depression or anxiety disorders, and one participant was subsequently excluded due to invalid data collection (data failed to record) in the dual task study. In the last instance, 39 people remained who completed the final experiment: 22 (11 female) were in the High-N group (mean EPQ score=18, range=16–24) and 17 (9 female) were in the Low-N group (mean EPQ score= 3.89, range=0–6). The two groups were approximately matched for age

(High-N = 21.36 and Low-N=23.50) and gender. All of the participants were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971) and had normal or corrected to normal vision. Each participant gave written informed consent and was paid £10. The study was approved by the Department of Life Sciences ethics committee at Brunel University.

3.2.2 Exclusion criteria for selection of high and low neurotics

To assess mood, personality, family background and life experience, participants were interviewed using the Hamilton Depression Rating Scale (Hamilton, 1967) and completed the following questionnaires: the Beck Depression Inventory (Beck et al., 1988), the EPQ (H. J. Eysenck & Eysenck, 1975), a history of past/current psychiatric or neurologic disorders questionnaire, alcohol consumption inventory, and a caffeine consumption inventory. People were excluded who had the presence of any past or current major medical, neurological or psychiatric illness that might have diminished their cognitive functioning; used psychoactive medication; had consumed alcohol before the study; consumed ≥8 cups of coffee/tea (or ≥ 900mg caffeine); scored over 15 in the Beck depression inventory (BDI), or showed colour blindness (Ishihara, 1936; Ishihara, 1987).

3.2.3 Stimuli

120 faces (60 female) were used in the visual task conditions. The images were black and white. Each image was presented for 345 ms. In the auditory task condition, there were 60 syllable stimuli, which comprised 30 different /haha/ and /yaya/ double-syllables. Each syllable was 345 ms long.

3.2.4 Tasks

Participants had to perform single-tasks and dual-task conditions in separate blocks. In the study the experiment session started with practice blocks for each condition before the main experiment started.

3.2.4.1 Single tasks (ST)

The visual single task consisted of 60 trials divided into 2 blocks of 30 trials each. A trial in the VIS condition started with a blank grey screen for 350 ms., followed by a fixation cross period of 300 ms. and the presentation of a male or female face for 345 ms. The overall trial duration depended on the response speed of the participant. Following each trial, either error feedback ("Error") or a fixation cross was displayed (300 ms). Thus, the interval between the last response and the onset of next stimulus (Response-Stimulus-Interval, RSI) was always 1300ms. The key mapping was set ‘N’ for responding to male faces and ‘M’ for responding to female faces. A trial in the auditory single task was identical to the visual single task except for the following. After the fixation period, a syllable haha or yaya tone was presented for ~345ms. The key mapping was set ‘X’ for responding to ‘ha\ha’ and ‘Z’ for responding to ‘ya\ya’ syllables.

3.2.4.2 Dual tasks (DT)

There was a fixed and a random dual task condition. The fixed dual task condition was presented either with long SOA or short SOA tasks in separate blocks. The random condition was presented with short SOA in separate blocks.

3.2.4.2.1 Fixed dual tasks

The study included two fixed dual tasks, which were DT 0 SOA and DT 1000 SOA. The fixed order dual task consisted of four blocks and each block included 30 trials. Thus there was 120 fixed order dual task trials in total.

In the short SOA dual tasks, the DT (syllable=>face) consisted of 1 block of 30 trials that included a syllable and a face (syllable=>face) that were presented simultaneously. DT (face=> syllable) was identical to DT (syllable=>face) except for the order of the stimuli, which were reversed.

In the long SOA dual tasks, DT (visual=>auditory) SOA1000 was identical to DT (visual=>auditory) SOA 0 except for 1000 SOA because the faces were presented at first and after 1000ms SOA the second syllables were presented. Similarly, DT (auditory =>visual) 1000 was identical to DT (auditory =>visual) SOA 0 except for the order of the stimuli; the syllables were presented first and after 1000ms SOA the second faces were presented.

Generally, in the dual task condition, the timing for the stimuli onset is described as short and long SOA tasks. The trial started with a fixation cross for 300 ms. The stimuli were presented and the response registration was started. The stimulus duration was 300ms for the faces and 300ms for the syllables. Responses were registered for a maximum of 4000ms, starting from the onset of the first stimulus (i.e. from item 2 on this list). At SOA0, this leaves 4000ms to respond to both stimuli. At SOA1000, the available time to respond is 4000ms to stimulus1 and 3000ms to stimulus 2 (all durations relative to onset of stimulus). Response registration was terminated either after 4000ms or after the number of required responses had been registered. Thus, the trial duration depended on the response speed of the participant. Then, either error feedback ("Error") or a fixation cross (which blends neatly into the fixation cross of item 1 of the next trial) was displayed. The duration of this error feedback / fixation cross was 300 ms. Thus, the interval between the last response and the onset of the next stimulus (Response-Stimulus-Interval, RSI) was always 1300ms. In total, a trial could last, at the maximum, for: 1000ms + 4000ms + 300ms = 5300ms.

3.2.4.2.2 Random tasks (RND)

The random tasks included four blocks and each block consisted of 30 trials. In this condition the task order varied randomly from trial-to-trial. The task order was counter balanced such that in 50% of the trials (syllable=>face) and in the other half (face => syllable). In the random task condition, the faces were cued with either blue or yellow coloured frames. In the RND task, face => syllable had a blue frame and in the syllable=>face trials there was a yellow frame. Both stimuli, the syllable and the face, were presented simultaneously. Furthermore, the characteristics of the random tasks were identical to the short SOA fixed order dual task.

3.2.5 Procedure

At the start of the study, all of the participants were read the information sheet and gave written consent to participate (see appendix E). After completing the screening procedure, participants who scored either over 16 or below 6 on the EPQ-R Neuroticism scale were invited to participate in the main study. After completion of the questionnaires related to the exclusion criteria (see section 3.2.1) the experiment started. While sitting on the chair in the cubicle room, the participants performed a PRP-type dual task consisting of two-choice response tasks, one auditory and one visual, in addition to the single tasks (Fig. 3.1.). There were two sessions, the practice and study sessions.

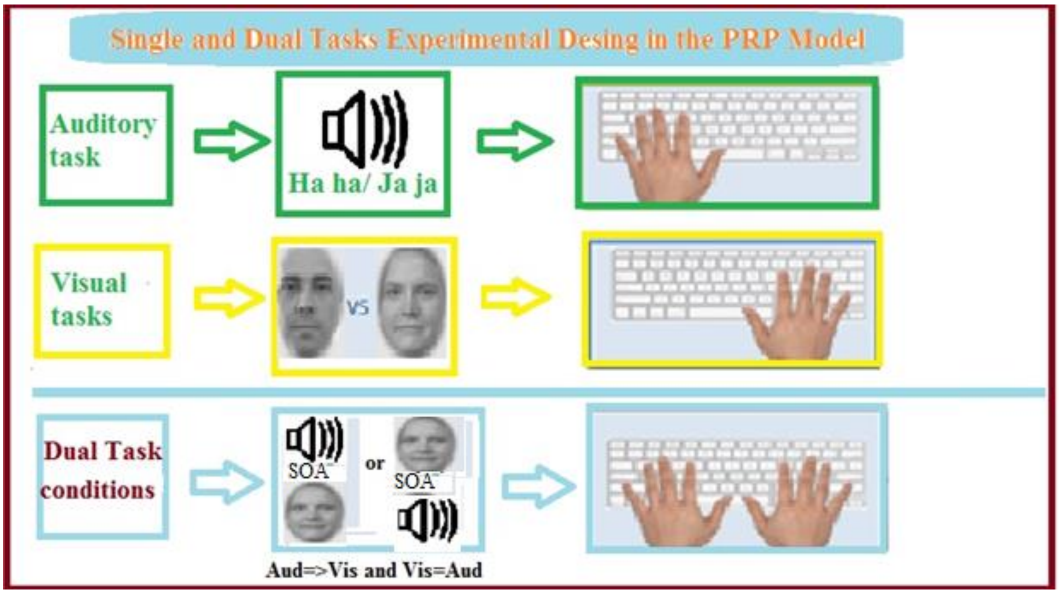

Figure 3-1 shows dual task experimental design including audio shown in green box and visual tasks shown in yellow box. Finally, the dual task was a combination of the two single tasks shown in the blue box.

In the practice session the participants performed the single, fixed order and random dual task conditions separately for around 15 minutes. After the practice session had been completed, the main study conditions started. The participants performed each task separately and all of the single and dual task conditions were counterbalanced across the study.

The visual single task participants viewed the male and female faces. The participants responded with their right index finger to the male face by pressing the N button and with the right middle finger to the female face by pressing the M button on the keyboard. In the auditory single task, the participants had to respond to the syllable ‘ha ha’ with their left index finger by pressing X and to the syllable ‘ya ya’ with the left middle finger by pressing the Z button on the keyboard. The other characteristics of the procedure were identical to the conditions of the VIS.

In the fixed dual task condition, the participants had to perform both tasks in each trial. Both stimuli (auditory and visual) were either presented simultaneously (SOA 0) or with an SOA of 1000. Participants were instructed in which order to respond (auditory⇒visual or visual⇒auditory) for the upcoming tasks. For example, in the auditory⇒visual condition, the participants had to respond first to the auditory task and then, immediately, to the visual task. For the 1000ms SOA condition the required response order was always identical to the order of presentation. For example, in the auditory⇒visual condition, the auditory task was presented first and thus the participants had to respond to the auditory task and after 1000 ms. the visual task was presented and the participants had to respond immediately to the visual task. Participants were instructed to respond to both tasks as fast and as accurately as possible. All other characteristics were identical to the single-task conditions.

In the random task condition, the response order was cued by the frame colour; either a blue or yellow frame in which the face was presented in the SOA 0 condition. If the frame was yellow, the participants responded to the syllable and then the face and if the frame was blue the participants responded to the face and then the syllable. For that purpose, both stimuli (auditory and visual) were presented simultaneously. The other characteristics of the procedure were identical to the short SOA fixed dual task. At the end of the study all of the participants were given a debriefing form (see appendix F).

Overall the study took one hour for each participant.

3.2.6 Data analysis

If not otherwise noted, in the following analyses, an analysis of variance (ANOVA) mixed design was used. The significant effects for the AVOVA tests were reported at $p< .05$ unless otherwise stated. The between-subject independent variable was Neuroticism (High-N vs. Low-N). The within-subject variables were the different task conditions and these varied between analyses. They will be described in the Results section. The dependent variables were the response times and error rates. In the all ANOVA tests **Levene's test** for equality of variances were considered. Because **Levene's test** for equality of variances were always not significant, normal ANOVA results were reported.

3.3 Results

3.3.1 Single task

Group Statistics					
	Groups	N	Mean RT (ms)	Std. Deviation	Std. Error Mean
SINGLE TASK	High N	22	579	90	19.30
	Low N	17	544	68	16.02

Table 3-1 Response times for participants with high levels of neuroticism (High-N,) and low levels of neuroticism (Low-N). Single Tasks is the average of both single tasks.

Independent t tests revealed insignificant differences between high and low neurotics for the average auditory and visual single tasks [$t\ (39) = 1.41; p > .05$]. These results indicate that the high and low neurotics did not differ in a statistically significant way in terms of their reaction times in the single tasks (see table 3.1.).

3.3.2 PRP effect

Descriptive Statistics				
	Groups	RT2 Mean	Std. Deviation	N
Short SOA (0ms)	High N	1466	303	22
	Low N	1219	217	17
Long SOA (1000 ms)	High N	848	240	22
	Low N	734	190	17

Table 3-2 Response times of short SOA and long SOA for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Short SOA is the average of both 0 SOA dual-task response orders (response times were taken from the second task auditory=>visual/visual=>auditory in the dual-task). Likewise, the Long SOA is the average of both 1000ms SOA dual-task response orders (auditory=>visual/visual=>auditory). The PRP effect is derived from the subtraction of RT2 short and long SOA (DT0-DT1000).

To test first hypothesis (hypothesis I: high neurotics will show a greater PRP effect compared to low neurotics) I calculated a 2x2 factorial ANOVA with the within-subject factor SOA (0 vs. 1000ms) and the between subject factor group (High N vs Low N). The results show that on average the high neurotics were slower than the low neurotics [main effect neuroticism; $F\ (1, 38) = 6.12; p < .05$]. Furthermore, a PRP-effect was evident, as illustrated by the on average slower RTs in the short SOA compared to the long SOA [main effect SOA; $F\ (1, 38) = 298.25; p < .05$]. Finally, the PRP-effect was larger for the high neurotics than for the low neurotics, as is evident by the interaction between the group and SOA [$F\ (1, 38) = 4.24; p < .05$] (see table 3.2). The significant interaction confirms my first hypothesis and shows that indeed the high neurotics had higher DT costs in the form of PRP effect than the low neurotics (Figure 3.2).

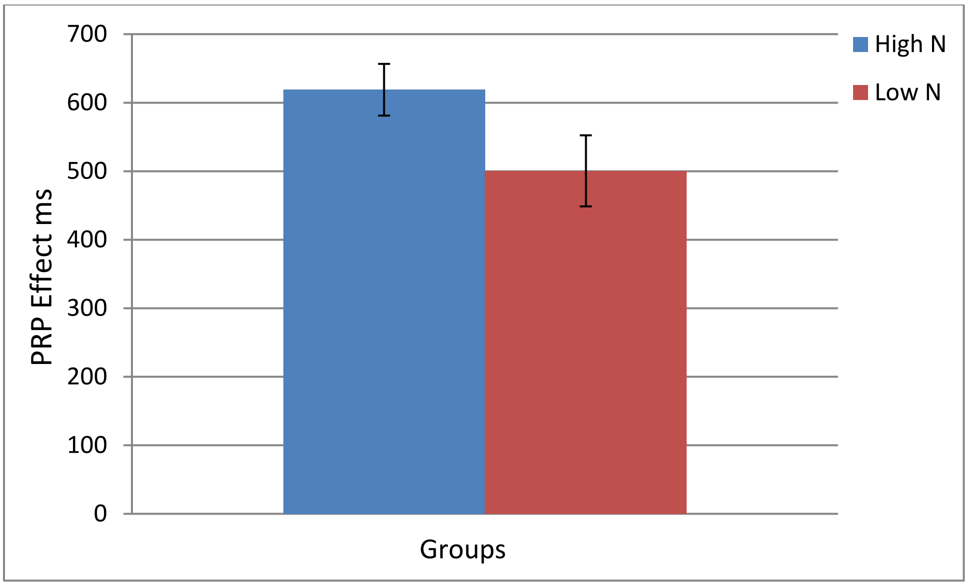

Figure 3-2 Shows mean PRP effect (ms) for high neurotics (High-N, blue column) and low neurotics (Low-N, red column). The PRP effect is derived from the subtraction of RT2 short and long SOA (DT0-DT1000). The mean PRP effect is taken from the average of the PRP of auditory =>visual and visual=>auditory.

3.3.3 Dual task combinations costs

In this section, I present the interaction effects between the RT of the single and dual tasks and the neuroticism levels. Because I took variables from the dual tasks and single tasks and then explored the interaction with neuroticism, I call these analyses 'the dual task combination costs'. Regarding the dual task cost, I only present analyses of RT 2 because this seems to be the most sensitive measure (Pashler, 1994a; Schubert & Szameitat, 2003; Szameitat et al., 2011). To test the second hypothesis (high neurotics will show a higher dual task combination cost than low neurotics in the processing of dual tasks whereas no difference will be found between the groups in single tasks), I calculated a 2x2 factorial ANOVA with the within-subject factor dual task cost (dual-task RT2 vs Single task) and the between subject factor group (High-N vs Low-N). The results show that on average the high neurotics were slower than the low neurotics [main effect neuroticism; $F(1, 38) = 5.61$; $p < .05$]. Furthermore, the dual task combination cost was evident, as illustrated by the on average slower RTs in the short SOA compared to the single task [main effect dual task combination costs $F(1, 38) = 323.09$; $p < .05$]. Finally, the dual task combination cost was larger for the high neurotics than for the low neurotics compared to the single task, as is evident by the interaction between the group and dual task combination costs [$F(1, 38) = 6.07$; $p < .05$] (see table 3.2). The significant interaction confirms my second hypothesis and shows that indeed the high neurotics had higher dual task costs in the form of so-called dual task combination-costs than the low neurotics (see figure 3.3.).

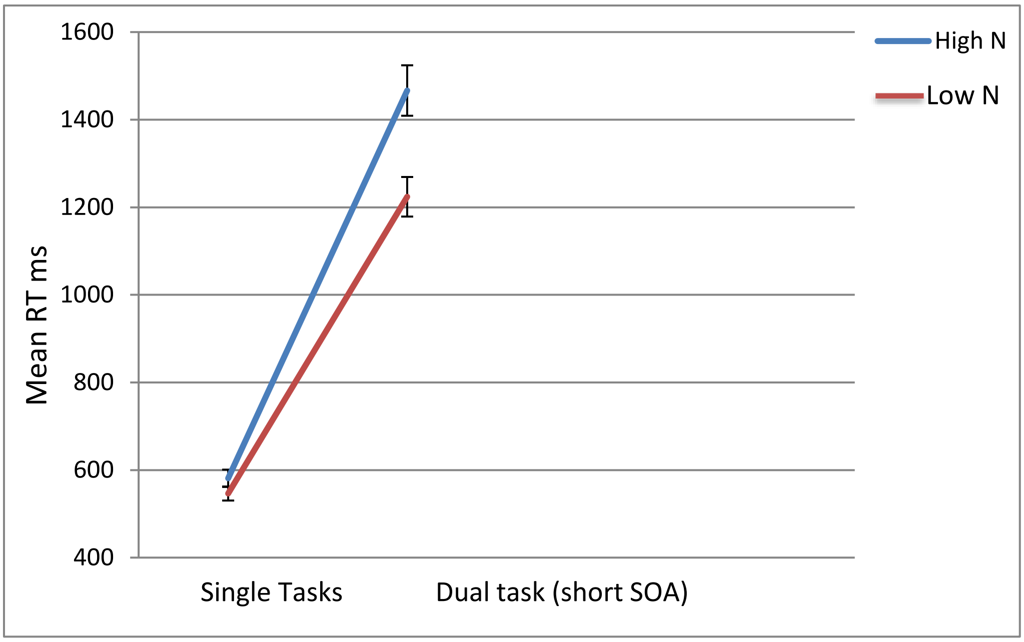

Figure 3-3 Shows response times for high neurotics (High-N, blue line) and low neurotics (Low-N, red line). Single Task is the average of both single tasks. Dual Task is the average of both dual-task response orders (response times were taken from the second task of the dual task

3.3.4 SOA effect on dual task combination costs

Descriptive Statistics				
	Groups	RT2-ST Mean (ms)	Std. Deviation	N
DT (SOA 0) -ST	high	886	248	22
	low	681	196	17
DT (SOA 1000) -ST	high	268	189	22
	low	195	141	17

Table 3-3 show descriptive statistics regarding neuroticism effect on SOA manipulation. DT cost is derived by subtracting ST from DT (DT-ST) for short and long SOA separately. Response times of DT0-ST and Dt1000-ST for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N).

Table 3-3 were also shown in the form of boxplot to assist configure mean and SD through tasks in high and low neurotics.

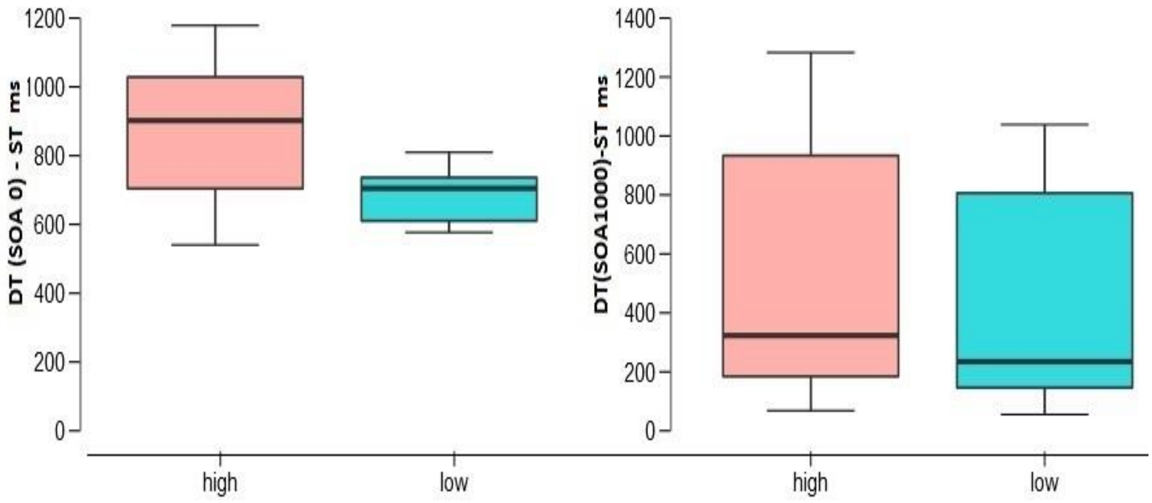

Figure 3-4 shows dual task combination costs (short and long SOA tasks) regarding mean and SD for participants high (pink box) and low (blue box) in neuroticism level. Note that different scales have been used for each variable.

In this section, I present the interaction effects between the SOA manipulations and the neuroticism levels, not with respect to the PRP effect (section 3.3.2) but with respect to the dual-task combination costs in the long and short SOA tasks. The dual task combination costs have been calculated by subtracting the single tasks RTs from the dual task RT2. Similar to the previous analyses, to test third hypothesis (the dual task combination cost differences between high and low neurotics will be greater for short SOA than long SOA tasks) I calculated a 2x2 factorial ANOVA with the within-subject factor SOA (short vs long) and the between subject factor group (High-N vs Low-N). The results show that on average the high neurotics had a greater dual task cost compared to the low neurotics during the dual task processing [neuroticism main effect $F(1, 38) = 7.95$; $p < .05$]. The dual task combination cost was evident, as illustrated by the on average slower RTs in the short SOA compared to the long SOA task [main effect SOA; $F(1, 38) = 298.25$; $p < .05$]. Finally, the dual task combination cost was larger for the high neurotics than the low neurotics as the SOA decrease, as is evident by the interaction between the group and SOA [$F(1, 38) = 4.24$; $p < .05$] (see table 3.3). The significant interaction confirms my third hypothesis and shows that indeed the high neurotics had higher DT costs in the short SOA in the form of dual task combination costs than the low neurotics (see figure 3.4.).

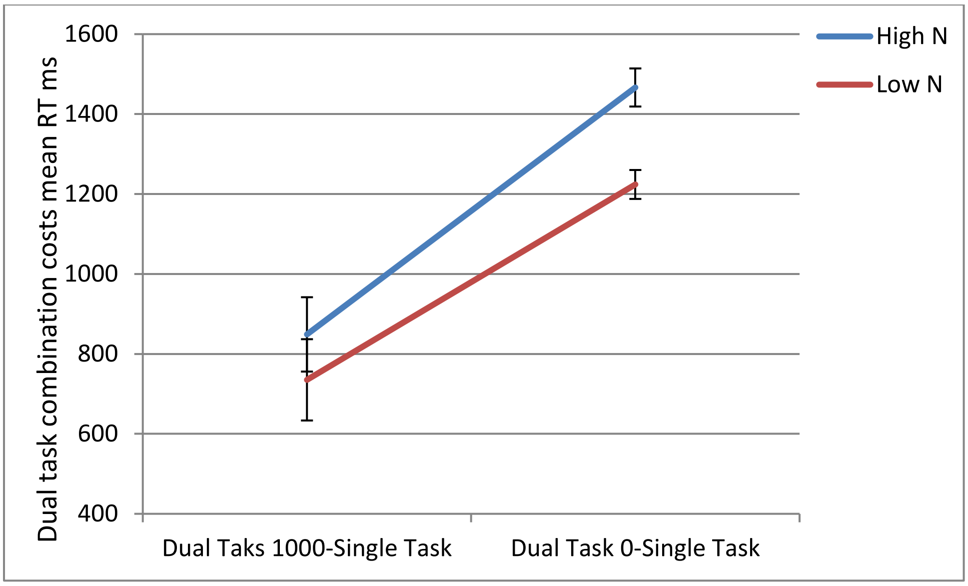

Figure 3-5 Shows response times regarding SOA effects on neuroticism. DT cost is derived by subtracting ST from DT (DT-ST,) for the short and long SOA separately. Response times of DT0-ST and Dt1000-ST for participants with high levels of neuroticism (High-N, blue line) and low levels of neuroticism (Low-N, blue line).

3.3.5 Random task

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
Repeating order RT1	High-N	1411.98	282.96	22
	Low-N	1269.79	258.42	17
Switching order RT1	High-N	1666.98	282.96	22
	Low-N	1400.00	258.15	17
Repeated trials RT2	High N	1740.12	322.55	22
	Low N	1551.00	299.46	17
Switched trials RT2	High N	2002.10	303.02	22
	Low N	1711.81	377.24	17

Table 3-4 shows descriptive statistics regarding neuroticism effect on repeated and switched trials for RT1 and RT2. Repeated and switched trials are derived from random tasks. Response times of repeated trials and switched trials for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N).

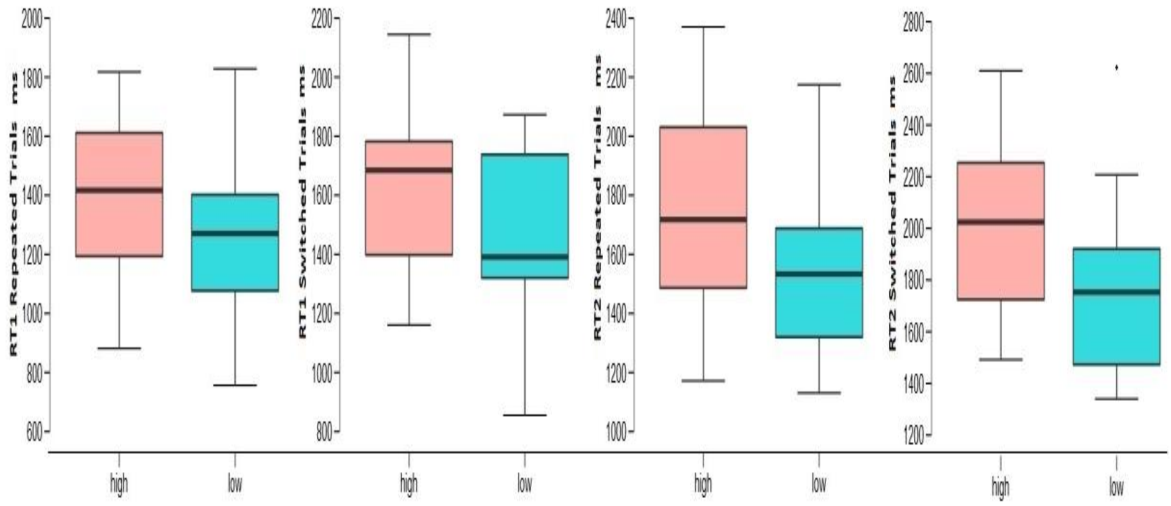

Figure 3-6 shows dual task costs in repeated and switched trials for RT1 and RT2 in random task regarding mean and SD for participants high (pink box) and low (blue box) in neuroticism level. Note that each result has been presented with a different scale.

To test the fourth hypothesis ‘The switching cost will be higher in high neurotics compared to low neurotics in a random task (switched trials vs repeated trials)’, I calculated a 2x2 factorial ANOVA with the within-subject factor RND (RT 1 switched trials vs. RT 1 repeated trials) and the between subject factor group (High-N vs Low-N). The results for RT1 show that on average the high neurotics were slower than the low neurotics [main effect neuroticism; $F(1, 38) = 6.31$; $p < .05$]. Furthermore, switching cost in the RND trials was evident, as illustrated by the on average slower RTs in the switched trials compared to the repeated trials [main effect RND trials; $F(1, 38) = 52.73$; $p < .01$]. Finally, the switching cost was larger for the high neurotics than for the low neurotics, as is evident by the interaction between the group and RND trials [$F(1, 38) = 5.56$; $p < .05$] (see table 3.4). The significant interaction confirms my fourth hypothesis and shows that indeed the high neurotics had higher switching costs in the RND trials than the low neurotics (Figure 3.5).

Figure 3-7 Repeated order trials were taken from RND trials which have same orders. Switched orders indicate the orders that shifted in the RND trials. First response times of repeat orders and switch orders for participants with high levels of neuroticism (High-N, blue line) and low levels of neuroticism (Low-N, blue line).

Same analyses were calculated for the RT2 switched trials vs. the RT 2 repeated trials. The results for RT2 show that on average the high neurotics were slower than the low neurotics [main effect neuroticism; $F(1, 38) = 6.57$; $p < .05$]. Furthermore, switching cost in the RND trials was evident, as illustrated by the on average slower RTs in the switched trials compared to the repeated trials [main effect RND trials; $F(1, 38) = 36.17$; $p < .05$]. Finally, although there was a trend that shows the switching cost was larger for the high neurotics than for the low neurotics, the interaction did not reach statistically significant level between the group and RND trials [$F(1, 38) = 2.66$; $p = .1$] (see table 3.4). The result is in support of my fourth hypothesis as evident by the trend that shows that indeed high neurotics had higher switching costs in the RND trials than low neurotics (Figure 3.6).

Figure 3-8 Second response times of repeat orders and switch orders for participants with high levels of neuroticism (High-N, blue line) and low levels of neuroticism (Low-N, blue line).

3.3.6 Error rates

I have used independent t test for analysis error rates in high and low neurotics for fixed and random dual task combination costs. Although these results shown below are not directly related my hypothesis, they are helpful to interpret results from above section (3.3.5, 3.3.4, and 3.3.2).

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
Single Task	High N	.053	.038	20
	Low N	.062	.039	17
Dual Task (SOA 0)	High N	.075	.047	20
	Low N	.085	.131	17
Dual Task (SOA1000)	High N	.075	.059	20
	Low N	.059	.050	17

Table 3-5 shows descriptive statistics regarding error rates for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Single Task is the average of both single tasks. Dual Task is the average of both dual-task response orders (response times were taken from the second task in the dual-task).

For the single tasks, as expected, the high and low neurotics did not differ regarding the error rates [t (39) = -.55; p > .05]. This result indicates that high and low neurotics execute a similar number of errors during the processing of single tasks.

To test second and third hypotheses in terms of error rates in high and low neurotics I used independent t test. The error rates in the fixed dual task performance for the high and low neurotics did not differ statistically; (main effect group: [F (1, 38) = .06; p > .05]; main effect SOA: [F (1, 38) = 3.56; p <.05]; interaction: [F (1, 38) = 1.60; p > .05]) (see table 3.5).

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
Repeated order R1	High-N	.053	.049	22
	Low-N	.052	.054	17
Switched order R1	High-N	.089	.068	22
	Low-N	.066	.072	17
Repeated order R2	High N	.090	.051	22
	Low N	.070	.055	17
Switched order R2	High N	.120	.080	22
	Low N	.070	.050	17

Table 3-6 shows descriptive statistics regarding neuroticism effect on repeated and switched trials for error rates in response 1 and 2. Repeated and switched trials are derived from random tasks. Error rates of repeated trials and switched trials for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N).

A comparable analysis of the error rates by independent t test in the RND trials for R1 (repeated order/Switch order) for the high and low neurotics is revealed the same general pattern of combination cost results which supports results related to hypothesis 4. However, the results did not always (RND trials: repeated order/Switched order is significant) reach statistical significance (main effect neuroticism: [F (1, 38) = .43; p > .05]; main effect RND trials: [F (1, 38) = 38; p <.05]; interaction: [F (1, 38) = 1.95; p =1.15]). Furthermore, the cost differences between high and low neurotics regarding error rates in the RND trials (R2) (repeated order/Switched order) revealed the same general pattern of combination cost results. However, the significance level remained (RND trials: repeated order/Switch order is significant) at the threshold of statistical significance (main effect neuroticism: [F (1, 38) = .43; p = .07]; main effect RND trials: [F (1, 38) = 7.30; p <.05]; interaction: [F (1, 38) = 2.69; p =0.06]) (see table 3.6 and see figure 3.7).

Figure 3-9 Show error rates from repeated to switched trials. Error rates of repeated trials and switched trials (R2) for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N).

3.4 Discussion

In line with the earlier findings related to the classical PRP effect (Logan & Gordon, 2001; Pashler, 1994a; Pashler, 1994b; Pashler et al., 2001), I observed the PRP effect during the processing of the tasks in all of the participants. Also, the task demand manipulation showed that the participants become slower as the demand increased. Further results showed that the high neurotics had a greater PRP effect, dual task combination cost, and switching cost than the low neurotics but the high and low neurotics did not differ statistically in the single tasks. The high neurotics showed higher task impairment as the demand increased respectively in the dual task combination cost (single/dual task), SOA (long/short), and parametric (random) manipulations. In line with these results, a general pattern of combination costs (for averaging short and long SOA dual tasks), and switching costs regarding RTs was found for the error rates, which, however, did not always reach a significant threshold for combination costs and remained at the significance threshold for switching costs.

The first hypothesis was that high neurotics have a greater PRP effect than low neurotics in dual task processing. This hypothesis is confirmed because I found that the high neurotics had a considerably larger PRP effect than the low neurotics. As indicated, the bottleneck can process each task one at a time when two tasks are presented simultaneously and this is why a delay occurs during the processing of the tasks (Logan & Gordon, 2001; Pashler, 1994b). Therefore, the results indicate that although both high and low neurotics encounter a delay due to the bottleneck, the delay is longer in high neurotics. This additional delay may be caused by worry and a higher arousal level, which leads to task irrelevant activities during dual task processing in high neurotics (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). It has been suggested that task demand on the CES causes reduced processing efficiency due to the detrimental effect of neuroticism when such tasks are performed in high neurotics (M. W. Eysenck et al., 2007).

To understand whether this additional delay in high neurotics is caused by task demand I compared the group's performance regarding their reaction times on the single and dual tasks, which is referred to as the dual task combination cost results. I assessed the single task as a simple task that requires virtually no CES function whereas the dual task was a demanding task that required extensive use of the CES functions (De Jong, 1995b; Monsell, 2003). The hypothesis was that high neurotics have a greater cost on the dual task whereas the high and low neurotics do not differ on the single task. These results showed that while the high and low neurotics both showed profound dual-task costs, i.e. a slowing of DTs compared to STs, these dual-task costs were considerably higher in the high neurotics. These results are in line with arousal based theory (H. J. Eysenck, 1967) and ACT (M. W. Eysenck et al., 2007) as they suggest that high neurotics show task impairment in demanding tasks (H. J. Eysenck, 1967) if they are associated with the CES functions (M. W. Eysenck et al., 2007) whereas high and low neurotics do not differ on simple tasks. These results provide a good insight into task processing in high and low neurotics compared with other studies that used two standard WM tasks as a dual task (Corr, 2003; M. W. Eysenck et al., 2005; Robinson & Tamir, 2005; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). Those studies usually used two standard memory tasks as dual tasks while one of these tasks was used as the single task (Baddeley, 1996a; Della Sala et al., 1995). This single task is somehow associated with WM (Baddeley, 1996a; Della Sala et al., 1995). However, Miyake et al. (2000) suggest that these types of dual tasks are not associated with the three main CES functions (switching, inhibition and updating). In this view, my results distinctively differentiate from those studies because I compared a single task (supposed to be non-CES) and a dual task (CES demands) in high and low neurotics. It is suggested that PRP dual task processing is strongly associated with the three main CES functions (switching, inhibition and updating) (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). I used a single task that was a very simple task requiring one response and the demand on the CES functions was minimized. The dual task was a combination of two simple tasks that were presented concurrently (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). This dual task was relatively demanding and required extensive use of the CES functions (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). Taken together, the results are in line with ACT (Derakshan & Eysenck, 2009) and the arousal based theory of neuroticism (H. J. Eysenck, 1967), which suggests that high neurotics show higher impairment than low neurotics in dual tasks compared to single tasks.

The third hypothesis was that high neurotics have a greater impairment than low neurotics as the SOA decreases in dual task processing. The results confirmed this hypothesis by showing a strong interaction between neuroticism and SOA manipulation. Thus, the dual task combination cost differences between the high and low neurotics became larger as the SOA decreased, as is evident from the higher dual task cost in high neurotics. Several studies have suggested that there is competition for processing by the bottleneck when the SOA is short in dual task performance (Jiang, 2004). This competition becomes more intensive as the SOA decreases, and thus a higher dual task cost occurs due to the delay in processing task 2 while task 1 remains relatively unaffected (Jiang, 2004; Szameitat et al., 2011). According to De Jong, (1995a), when the SOA is long, the demand on the switching and inhibition functions is lower, and therefore the participants have an optimal time to switch tasks and inhibit irrelevant contexts. However, in the short SOA there is not time to be prepared sufficiently for switching one task and inhibiting other task (De Jong, 1995b; Monsell, 2003). The results demonstrated that the high neurotics were slower than the low neurotics, as is evident by the higher cost in both the long and short SOA tasks. Furthermore, the cost in the high neurotics became more pronounced in the short SOA tasks and thus the differences between the high and low neurotics reached a greater level in the short SOA tasks in favour of the low neurotics. In detail, when the SOA was increased to 1000ms, even though the high neurotics were still slower than the low neurotics, the differences between the groups did not reach a statistically significant level because the performance of the high neurotics relatively improved compared to the short SOA tasks. Also, the performance of the low neurotics also improved, but the improvement was bigger in the high neurotics. Higher task impairment was also found regarding error rates (Baker et al., 1996; MacDonald et al., 2000). Generally, the high neurotics, numerically, executed higher error rates than the low neurotics. It has been suggested that efficient task processing requires faster RTs and lower error rates. In this context, the results indicate that as the SOA decreased in the dual task, the high neurotic participants showed a greater impairment in terms of processing efficiency of the tasks compared to the low neurotics. On the other hand, when an optimal time was given such as 1000ms SOA for the dual task processing, their performance relatively improved. It should be noted that numerically, in the short SOA tasks low neurotics made higher number of errors than the low neurotics and in the long SOA task the high neurotics made more errors than the low neurotics. However, these results were not significant. They may indicate that the high and low neurotics used different speed accuracy trade-off strategies but for the high neurotics using the strategy was not enough to compensate for the interference of task irrelevant activities during the task processing. Therefore, the low neurotics still had higher processing efficiency than the high neurotics. Other evidence for this interpretation is the analysis of the error rates in RND task below. It shows that the task demand increased and thus the high neurotics became worse in all conditions regarding error rates.

The last hypothesis was that high neurotics have higher switching costs than low neurotics in random condition trials. The results confirmed this hypothesis by showing that the high neurotics had higher task impairment in terms of both reaction times and error rates. In detail, there were the repeated order trials which the trials remain with same order and the switching order trials which task order changed. Comparisons of repeated and switched order trials in high and low neurotics show that high neurotics become slower and execute more errors than low neurotics. The results indicate that the high neurotics became slower and made more errors than the low neurotics in the switched trials compared to the repeated trials. The random condition was relatively the most demanding and stressful condition because it was performed with short SOA with an unexpected order (De Jong, 1995b; Luria & Meiran, 2003). Thus, it required higher control demand in relation to the switching and inhibition functions. According to Luria & Meiran, (2003) there is an ambiguity in the random condition that increases the demand on the switching function. The participants were required to resolve this ambiguity by consuming more time in the control processes than in the repeated order tasks (Luria & Meiran, 2003; Luria & Meiran, 2005). Finding higher RTs in switching cost trials as compared to repeated order trials is strong evidence that the participants encountered higher demand on the switching function because they struggled with the subtask order information during the online control (Luria & Meiran, 2003; Luria & Meiran, 2005). Also, De Jong (1995b) suggests that the bottleneck mechanism (preparation) is automatically set to the task which came first in the last trial. Thus, if the order changes in the current trial, the bottleneck is set to the wrong task and has to be switched once more (De Jong, 1993; De Jong, 1995b). In other words, in a switching order trial, there is one more switching operation of the bottleneck involved (De Jong, 1993; De Jong, 1995b). This switching may involve inhibition of the task and loading the S-R mapping. According to Luria & Meiran (2003 and 2005), in repeated task orders participants may take advantage of the setting the tasks automatically. Therefore, RTs and error rates may be higher in switched order trials than in repeated order trials (Luria & Meiran, 2003; Luria & Meiran, 2005). I found that the high neurotics were slower with higher error rates than the low neurotics in both the repeated and switched trials. Furthermore, the slowness and higher error rates were more pronounced in the switching trials than the repeated trials compared to the low neurotics. Taking into account ACT, which assumes that increased demand in the central executive system leads to an impairment in the processing of working memory tasks (M. W. Eysenck et al., 2007), because the task demand is considerably higher on the switching and inhibition functions, the impairment in the high neurotics became more pronounced compared to the low neurotics during the switching trials. In particular, if the task demand associated with the three main functions of the CES, (i.e. shifting, inhibition and updating), the task processing considerably impairs in high neurotics compared with low neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). In this study, the random dual task condition was mainly associated with shifting but it also involved the inhibition and updating functions (Stelzel, Kraft, Brandt, & Schubert, 2008b; Szameitat et al., 2002; Szameitat et al., 2016). Because both tasks were presented randomly and simultaneously the participants had to use the switching and inhibition functions extensively during the switching trials and also they need to update task related context (De Jong, 1995b; Luria & Meiran, 2005).

So far, the results in the present experiment indicate that high neurotics are slower and execute more errors than low neurotics as the CES demand increases. Moreover, the results show that when the demand increases on the switching and inhibition functions, the cost in high neurotics becomes more pronounced compared to low neurotics. According to the arousal based theory of neuroticism (H. J. Eysenck, 1967) and ACT (M. W. Eysenck et al., 2007), worry and a higher level of arousal cause task irrelevant activities in high neurotics during the processing of resources in demanding tasks. ACT (M. W. Eysenck et al., 2007) suggests that task irrelevant activities interfere with attention during resource processing; therefore, they impair the three main functions of the CES (inhibition, switching and updating). Taken together, an increase in CES demand is sufficient to show impairments in high neurotics in task processing. Because generally high neurotics are considerably slower and make more errors, task impairment in high neurotics can be concluded to be the result of lower processing efficiency. In the next study, I am going to replicate this study with different stimuli. The reason for that is that I used faces and syllables in the present experiment. The stimuli as such were rather neutral but they were social (faces and syllables) so that they may include some emotional cues. As indicated in section 1.7.1, task processing may be influenced by emotional cues and thus it may have an emotional/social component for high neurotics.

4 Chapter – Neuroticism related differences during processing of dual task with neutral stimuli

4.1 Introduction

The third experiment aimed to replicate the previous dual task findings (chapter 3) using a modified design. Replication of the results is important because it assures that results are valid and reliable which highlights generalizability of the results by using non-emotional stimuli; thus it provides new insights for next research.

The previous dual task consisted of faces and syllables which are potentially emotional stimuli. However, in the present study, I used non-emotional stimuli. Therefore, instead of faces, circles have been used as visual stimuli and instead of syllables, beep tones have been used as auditory stimuli. Below, I review previous cognitive studies that show emotional stimuli may influence RTs in high neurotics (Bishop, Duncan, Brett, & Lawrence, 2004; Dolcos & McCarthy, 2006; Hare et al., 2008). I argue that these studies show a potential contamination effect of emotional stimuli in cognitive processing, which may have affected the result of the previous study (see Chapter 3). In these studies, the effect of emotional stimuli in relation to neuroticism level are investigated either explicitly (i.e. participants are asked to recognize the emotional face whether it is happy or sad or angry) or implicitly (participants asked to decide whether a presented emotional face is the male or female) (M. W. Eysenck et al., 2007). In the previous dual task study (chapter 3), in visual single task, I asked participants to decide whether the presented face is male or female. In auditory single task, I asked participants to decide whether the syllable is ha/ha or ya/ya. Although these stimuli were not intentionally selected as emotional stimulus, they are social stimuli and so may include emotional cues. Further, this study is similar to the previous studies that measured effect of emotions implicitly. Therefore, in this chapter, I aim to exclude a possible effect of emotional stimuli and show the differences between high and low neurotics are really because of lower processing efficiency in cognitive processing of the task.

My prediction is that high neurotics will have lower processing efficiency than low neurotics in demanding cognitive tasks because higher CES demand increase worry and arousal levels in high neurotics thus detrimental effect of neuroticism impairs CES functions. However, some studies found that using emotional stimuli in cognitive tasks may cause higher task impairment than when using neutral stimuli (Bishop et al., 2004; Dolcos & McCarthy, 2006;

M. W. Eysenck et al., 2007). For example, two separate studies (MacLeod & Rutherford, 1992; Mogg, Bradley, Williams, & Mathews, 1993) conducted an emotional Stroop task with high and low neurotics. Their emotional Stroop task includes emotional and neutral stimuli. The results showed high neurotics were considerably slower than low neurotics when the task includes negative emotional stimuli compared to neutral stimuli. Another study conducted by Eysenck & Byrne (1992) is a visual search task. In this task participants required to found a certain face among the other faces. The results showed that high neurotics were slower when the target face had a happy expression as compared to a neutral one. Dolcos & McCarthy, (2006) conducted a delayed-response working memory task to explore effect of emotional stimuli in cognitive task processing (See section 1.5.2). The task includes neutral and negative emotional faces. Participants were found with lower processing efficiency when the task includes negative emotional stimuli than when the task includes neutral stimuli. These results may indicate emotional stimuli may contribute impairments in WM task processing. General interpretation for such results is that high neurotics more incline to affectivity; therefore they have selective attention bias towards emotional stimuli (Di Simplicio et al., 2014a; Di Simplicio, Norbury, & Harmer, 2012; Di Simplicio et al., 2014). Focusing on emotional stimulus may trigger worry that increase arousal level and thus it causes impairment in demanding cognitive tasks in high neurotics (Power & Dalgleish, 1997; Barnhofer & Chittka, 2010).

As Eysenck, (1967) suggested in high neurotics, higher arousal level cause task impairment in difficult task. Moreover, ACT indicates using of emotional stimuli in cognitive tasks may negatively influence task processing in high neurotics due to selective attention toward emotional stimuli (M. W. Eysenck et al., 2007). However, in this study, I would like to show greater task impairment in high neurotics is because of higher cognitive task demand (CES demand) and the impairment is not associated with emotional stimuli. As a consequence, in the dual task study (chapter 3) selective attention in high neurotics may have some effects on the results due to the stimulus i.e. that may influence on RTs in high or low neurotics. Therefore, in this chapter, I aim to exclude a possible effect of emotional stimuli and show the differences between high and low neurotics are really because of lower processing efficiency in cognitive processing of the task.

Taken together, the reason why faces and voices are changed to non-emotional stimuli is because it is known that emotional stimulus such as faces and voices influence cognitive processing in high neurotics (Canli, 2004). In chapter 3, the PRP dual task study is well controlled and it is unlikely that high and low neurotics differed, because in that study the male and female faces selected randomly without intending emotional induction.

I aimed to replicate the previous dual task experiment results. To do so I formulate three hypotheses as following:

I. PRP effect which indicates differences between RT2 in short and long SOA tasks will be grater in high neurotics than low neurotics.

II. High neurotics will have higher dual task cost (dual task combination of cost) comparing low neurotics during processing of dual tasks particularly in second task whereas no significant differences will be found on single tasks.

III. The dual task combination cost differences between high and low neurotics will be greater during processing of short SOA than long SOA particularly in the second task.

4.2 Methods

4.2.1 Participants

To create extreme groups of high- and low-neurotics (High-N and Low-N, respectively), I screened 345 students using the 24-item neuroticism scale of the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975) in Turkey/Diyarbakir Dicle University campus. From the selected participants as high and low neurotics, five participants were excluded because of current or previous depression or anxiety disorders (2 High N and 3 Low N). Two participants were excluded because neurological disorders according to history of past or current psychiatric or neurologic disorders questionnaire (2 High N). Finally, from the N screened people, 42 people took part in the final experiment: 20 (7 female) were in the High-N group (mean EPQ score=18, range=16–24) and 22 (9 female) in the Low-N group (mean EPQ score= 3.89, range=0–6). The two groups were closely matched for age (High-N = 21.36 and Low-N=23.50) and gender. 40 participants were right handed and two participants were left handed as assessed by the Edinburgh Inventory (Oldfield, 1971). All participants had normal or corrected to normal vision. Before participation each participant gave written informed consent. Participants were paid 10TRY for 1-hour participation. The study was approved by the Department of Life Sciences ethics committee at Brunel University.

4.2.2 Exclusion criteria for selection of high and low neurotics

The exclusion criteria were identical to chapter 2 and 3.

4.2.3 Stimuli

There were two circles (blue and yellow) used in visual task conditions. Each circle was presented for 345 ms. In the auditory task condition, there were two pitch tones; high and low pitch tones. High pitch tones had 700Hz and low pitch tone had 400Hz. Each pitch tone was 345 ms long.

4.2.4 Tasks

There were single tasks that include auditory and visual single tasks. Fixed order dual tasks include short SOA tasks and long SOA tasks.

4.2.4.1 Single task

The task from the previous study (chapter 3) was used with the following changes. In this study visual stimuli (males and female faces) were changed to blue and yellow circles and syllables ("ha-ha" and "ya-ya") were changed to high and low pitch tones. In the visual single task, there were three blocks and each block consisted of 25 trials. In total visual single task consisted of 75 trials. The auditory single task was identical to the visual task with regards to blocks and trials. For the auditory task, the key mapping was 'X' for responding to the 'low pitch' and 'C' for responding to the 'high pitch' tones. For the visual task key mapping was sat 'N' for yellow circles and 'M' for blue circles.

4.2.4.2 Dual task

Participants performed a PRP-type dual task, consisting of two 2 alternative forced choice response tasks, one auditory and one visual (Fig. 1.). All conditions were identical to previous dual task study (chapter 3) except following changes. Dual tasks were comprised of the two single tasks described above. There were eight blocks of 25 trials. Four blocks employed short SOAs (two blocks for Circle=>Tone and two blocks for tone=>circle tasks) and four long SOAs (with same structure as short SOA blocks). The random task was not present in this experiment.

4.2.5 Procedure

The procedure was identical to previous dual task (chapter 3) except following changes. The experiment took places in a cubicle room that is located in medical school of Dicle University/Turkey. Participants filled Turkish version of EPQ and all other screening documents. Following by that participants performed a PRP-type dual task (similar as in chapter 3), which consist of two-choice response tasks, one auditory and one visual (Fig. 4.1.). In visual single task, participants were required to press 'N' for yellow circles and they have to press 'M' for blue circles. In auditory single task, they are required to press 'X' for low pitch and 'C' for high pitch tones. In dual tasks participants have to perform both single tasks either in a rapid succession (1000ms SOA) or simultaneously (0ms SOA).

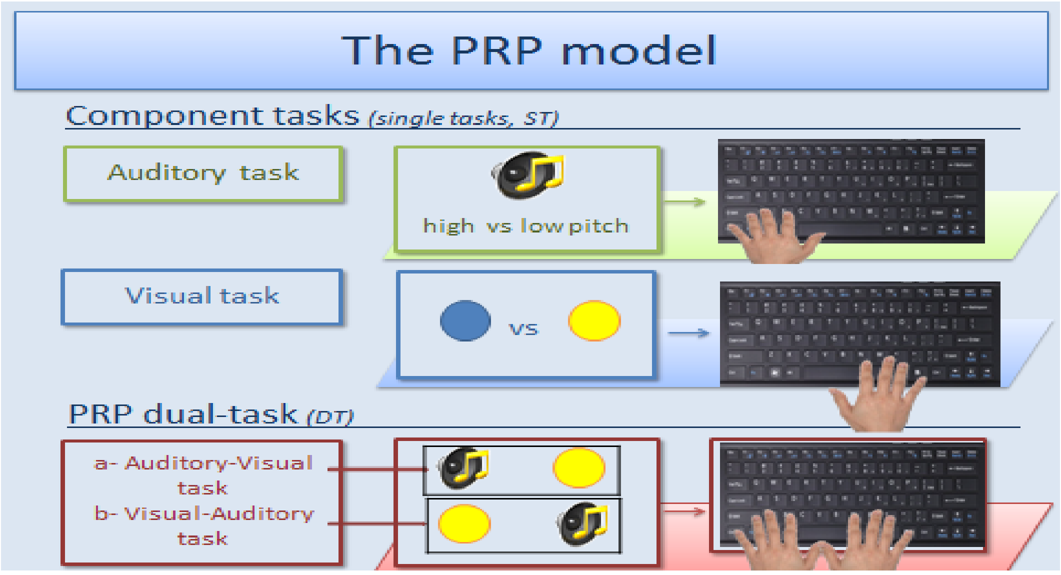

Figure 4-1 Shows auditory and visual two-choice response tasks in PRP-type dual task study. Auditory single task is shown in green outline box. Visual single task is shown in blue outline box. Finally, dual tasks are shown in red outline box.

4.2.6 Data analysis

If not otherwise noted, in the following analyses, either an independent t tests or mixed designs ANOVAs were used. Significance for t tests was calculated two-tailed and all effects were reported at $p < .05$ unless otherwise stated. The between-subject independent variable was EPQ-Neuroticism with the levels high and low neuroticism. The within-subject variables were the different task conditions and varied between analyses. They will be described in the Results section. The dependent variables were response times and error rates. In the all ANOVA tests **Levene's test** for equality of variances were considered. Because **Levene's test** for equality of variances were always not significant, normal ANOVA results were reported.

4.3 Results

4.3.1 Single task

Group Statistics					
	Groups	N	Mean RT	Std. Deviation	Std. Error Mean
Single Task	High N	20	551	76	16.99
	Low N	22	522	69	14.75

Table 4-1 Response times for participants with high levels of neuroticism (High-N,) and low levels of neuroticism (Low-N). Single Tasks is the average of both auditory and visual single tasks.

In line with the results reported in chapter 3, independent t tests demonstrated, although high neurotics were 29 ms slower than low neurotics on average, high and low neurotics did not significantly differ in reaction times average between auditory and visual single tasks [$t(42) = 1.69$; $p > .05$] (see table 4.1).

4.3.2 PRP effect

Descriptive Statistics				
	Groups	Mean RT	Std. Deviation	N
Short SOA (0)	High N	1330	286.69	20
	Low N	1141	274.57	22
Long SOA (1000 ms)	High N	712	200.13	20
	Low N	640	137.06	22

Table 4-2 Response times of short SOA and long SOA for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Short SOA is the average of both 0 SOA dual-task response orders (response times were taken from the second task tone=>circles/circles=>tone in the dual-task). Likewise, Long SOA is the average of both 1000ms SOA dual-task response orders (tone=>circles/circles=>tone). PRP effect is derived from subtraction of RT2 short and long SOA (DT0-DT1000)

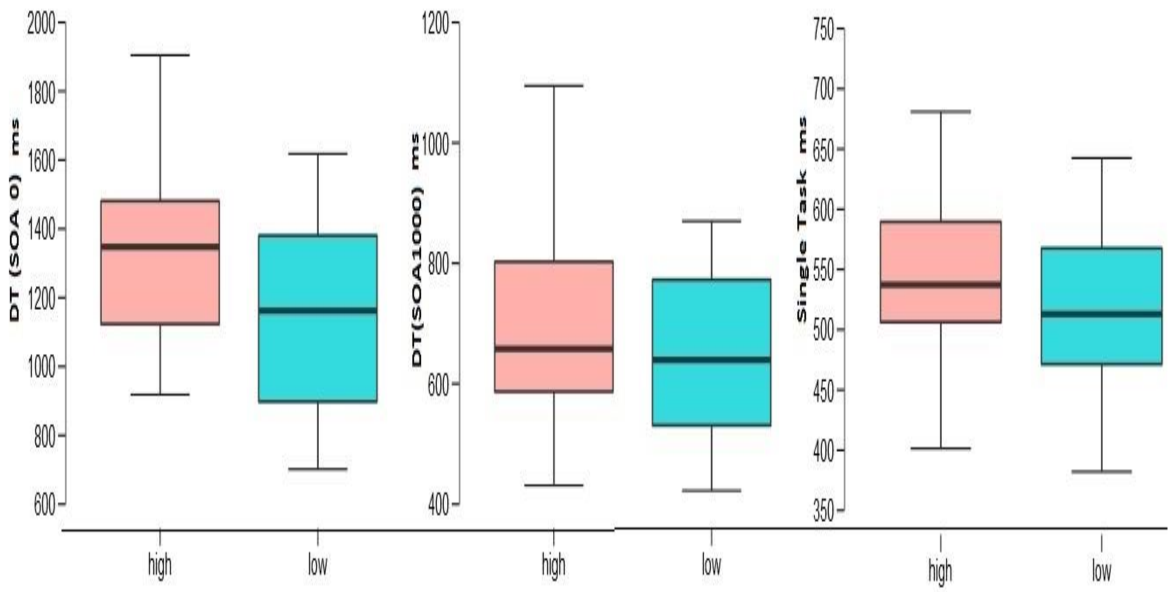

Figure 4-2 shows single and dual task costs in the form of boxplot regarding mean and SD for participants high (pink box) and low (blue box) neuroticism level. Note that each result has been presented with a different scale.

To test first hypothesis (PRP effect which indicates differences between RT2 in short and long SOA tasks will be grater in high neurotics than low neurotics), I calculated a 2x2 factorial ANOVA with the within-subject factor RT2 SOA (0 vs. 1000ms) and the between subject factor group (High-N vs Low-N). PRP effect is derived by subtraction RT2 long SOA from RT2 short SOA. Results showed that on average high neurotics were slower than low neurotics [neuroticism main effect, $F(1, 40) = 3.9$; $p < .05$]. Furthermore, a PRP-effect was evident, as illustrated by the on average slower RTs in the short SOA as compared to the long SOA [SOA main effect, $F(1, 40) = 443.95$; $p < .05$]. Finally, the PRP-effect was larger for the high neurotics than for the low neurotics, as evident by the interaction between group and SOA [$F(1, 40) = 4.89$; $p < .05$] (see table 4.2). The significant interaction confirms the first hypothesis by replicating the previous results (see section 3.3.2) and shows that indeed high neurotics have higher DT costs in form of a PRP effect than low neurotics regardless emotional stimuli effect (see figure 4.2).

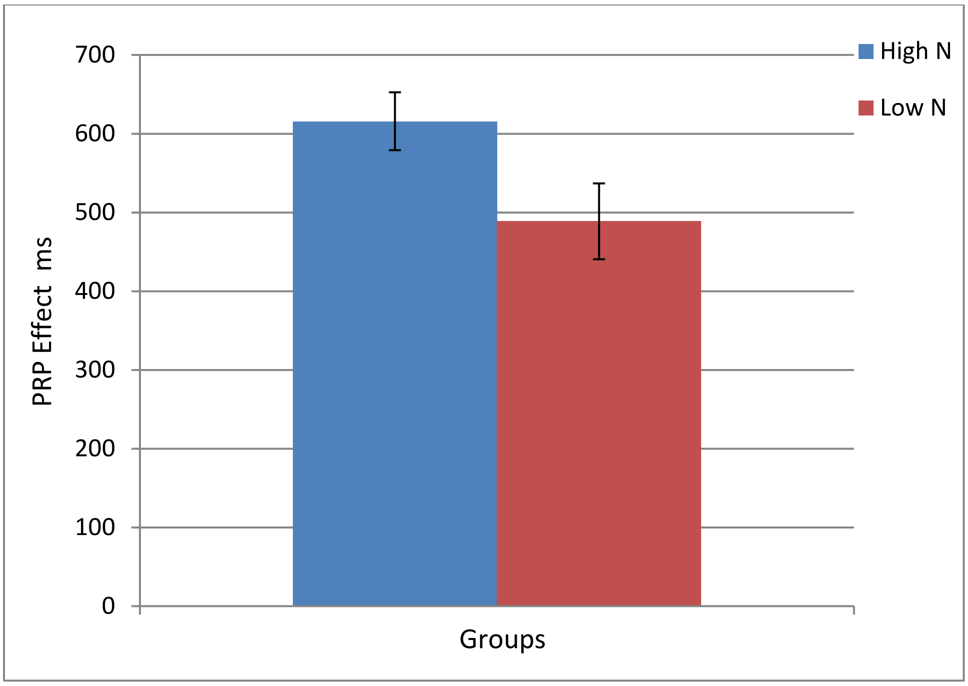

Figure 4-3 Shows mean PRP effect (ms) for participants with high levels of neuroticism (High-N, blue column) and low levels of neuroticism (Low-N, red column). PRP effect is derived from subtraction of RT2 short and long SOA (DT0-DT1000). Mean PRP effect is taken from average of PRP effects for each condition (tone=>circles and circles=>tone).

4.3.3 Dual task combination costs

In this section, I present interaction effects between RTs of single and RT2 dual tasks with short SOA and neuroticism levels. Regarding dual task cost, I only present analyses of RT 2 because majority of PRP studies found significant effects of RT 2. To test the second hypothesis (High neurotics will have higher dual task cost (dual task combination of cost) comparing low neurotics during processing of dual tasks particularly in second task whereas no significant differences will be found on single tasks), I calculated a 2x2 factorial ANOVA with the within-subject factor task (DT0 (RT2) vs Single task (RT)) and the between subject factor group (High-N vs Low-N). Results showed that on average high neurotics were slower than low neurotics [neuroticism main effect, $F (1, 40) = 4.39$; $p < .05$]. Furthermore, the cost in RT2 was evident, as illustrated by the on average slower RTs in the short SOA as compared to the single task [SOA main effect, $F (1, 40) = 373.09$; $p < .05$]. Finally, the dual task cost (RT2) was larger as compared to single task for the high neurotics than for the low neurotics, as evident by the interaction between group and SOA [$F (1, 40) = 4.84$; $p < .05$]. The significant interaction confirms the second hypothesis and shows that indeed high neurotics have higher dual task costs in form of a combination costs than low neurotics (see figure 4.3).

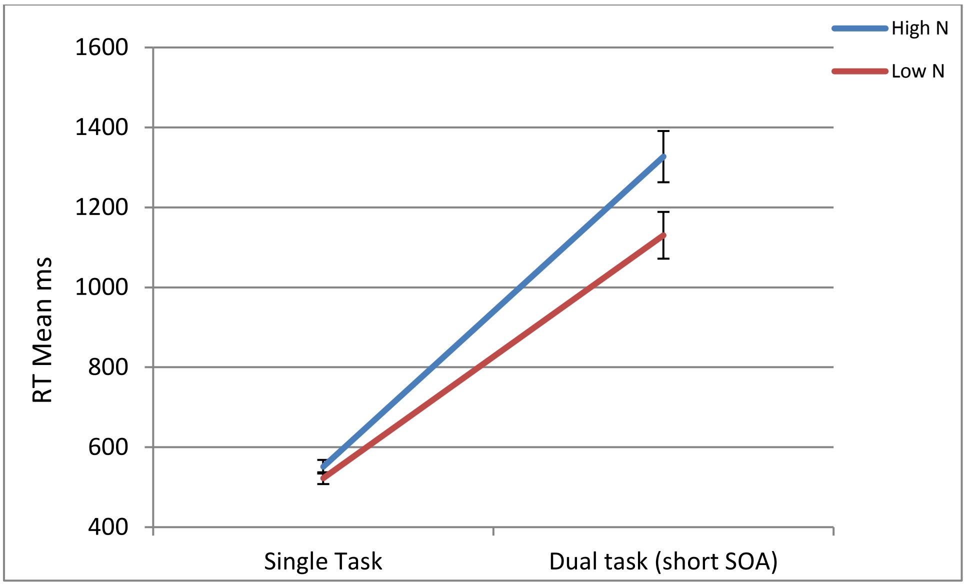

Figure 4-4 show response times for participants with high levels of neuroticism (High-N, blue line) and low levels of neuroticism (Low-N, red line). Single Tasks is the average of both single tasks. Dual Tasks is the average of both dual-task response orders (response times were taken from the second tasks in dual task).

4.3.4 SOA effect on dual task combination cost

Descriptive Statistics				
	Groups	Mean RT	Std. Deviation	N
DT (SOA 0) -ST	High N	778	235	20
	Low N	619	232	22
DT (SOA 1000) -ST	High N	618	164	20
	Low N	483	225	22

Table 4-3 show descriptive statistics regarding SOA effects on neuroticism. DT cost is derived by subtracting Single task (RTs) from Dual Task (RT2) for short and long SOA separately. Response times of (DT0 RT2-ST) and (DT1000 RT2-ST) for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N).

In this section, I present interaction effects between SOA manipulations and neuroticism levels. Dual task cost is calculated by subtracting single tasks from dual task RT2 for each SOA separately and then I explored interaction between SOA and neuroticism. Similar to previous analyses, to test the third hypothesis (The dual task combination cost differences between high and low neurotics will be greater during processing of short SOA than long SOA particularly in the second task), I calculated a 2x2 factorial ANOVA with the within-subject factor dual task cost (SOA 0 Dual Task RT2-Single task RT vs SOA 1000 Dual Task RT2-Single task RT) and the between subject factor group (High-N vs Low-N). Results showed that on average high neurotics have greater dual task cost compared to low neurotics [Neuroticism main effect, F (1, 40) = 4.94; p < .05]. Dual task combination cost was evident, as illustrated by the on average slower RTs in the short SOA as compared to the long SOA task [SOA main effect, F (1, 40) = 378.82; p < .05] Finally, the dual task combination cost was (RT2) larger at the lower SOA than for the high neurotics than for the low neurotics, as evident by the interaction between group and SOA [F (1, 40) = 5.24; p < .05] (see table 4.3). The significant interaction confirms my third hypothesis and shows that indeed high neurotics have higher costs at the short SOA in the form of dual task combination costs than low neurotics (see figure 4.4.).

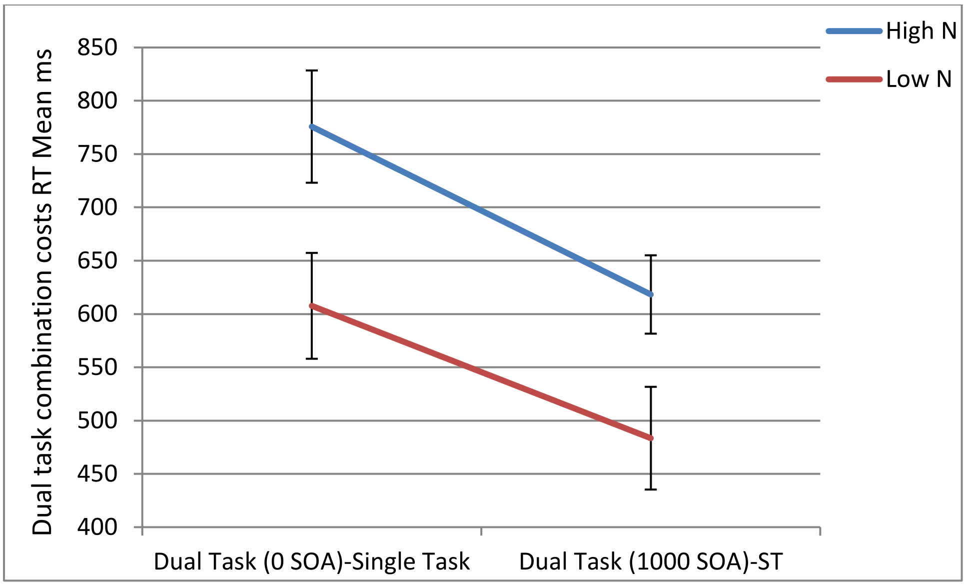

Figure 4-5 show SOA effects on neuroticism. DT cost is derived by subtracting ST from DT (DT-ST,) for short and long SOA separately. Response times of DT0-ST and Dt1000-ST for participants with high levels of neuroticism (High-N, blue line) and low levels of neuroticism (Low-N, red line).

4.3.5 Error rates

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
Single Task	High N	.035	.026	20
	Low N	.046	.051	22
Dual task (SOA 0)	High N	.048	.066	20
	Low N	.051	.035	22
Dual task (SOA 1000)	High N	.090	.075	20

	Low N	.198	.178	22

Table 4-4 shows descriptive statistics regarding error rates for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Single Tasks is the average of both single tasks. Dual Tasks is the average of both dual-task response orders (response times were taken from the second task in the dual-task).

Regarding single tasks, as it was expected, high and low neurotics were not differentiated statistically regarding error rates [F (1, 40) = 2.58; p > .05]. This result indicates that high and low neurotics roughly execute similar number of errors during processing of single tasks (see table 4.4).

Regarding dual tasks, a comparable analysis of error rates to error rates in chapter 3 revealed the similar general pattern of results regarding error rates in dual task costs which support my hypotheses (1-3), however it did not reach statistical significance (main effect group: [F (1, 40) = 1.68; p > .05]; main effect SOA: [F (1, 40) = 22.97; p <.05]; interaction: [F (1, 40) = 1.70; p > .05]) (see table 4.4).

4.4 Discussion

In line with the previous dual task study, I found PRP effect in all participants. Also, participants became slower as the task demand increased from single task to dual task and from long SOA tasks to short SOA task. I found high neurotics had larger PRP effect than low neurotics. Further, high neurotics had higher task impairment than low neurotics as the demand increase respectively in dual task combination costs (single/dual task), SOA (long/short). Regarding error rates, numerically, low neurotics made more errors than high neurotics based on the mean values however high and low neurotics did not statistically and significantly differ.

In this study, I removed face and syllable stimuli that may have a potential emotional effect during task processing in high neurotics. It has been suggested emotional stimulus may trigger stress that increase worry and arousal level in high neurotics (M. W. Eysenck et al., 2007; Power & Dalgleish, 1997). It is suggested that worry and higher arousal level impairs task processing in high neurotics (M. W. Eysenck et al., 2007) . One important question was whether worry and arousal level is increased because of any influence of emotional stimuli or it is because of pure demand on CES functions. According to Eysenck (1967) higher arousal and worry are more likely to associates with emotions in limbic system. In this context, it is reasonable if emotional stimuli increase worry and arousal level and cause task impairments. In line with that Eysenck et al., (2007) suggested emotional stimuli in cognitive task processing may have a considerable side effect regarding task performance in high neurotics. A few empirical studies showed that high and low neurotics may differently influenced by emotional stimuli in cognitive tasks (Bishop et al., 2004; Dolcos & McCarthy, 2006). Also, several emotional studies showed that when emotional stimuli (male and female faces) presented, high neurotics faster while responding negative emotional stimuli and slower to respond positive emotional stimuli (Canli et al., 2001; Haas et al., 2007). Using such stimuli in a cognitive task may affect response times in high neurotics, because the experimental procedure is very similar i.e. participants decide whether an affective face is male or female in emotional tasks thus effect of emotions is investigated in implicit way (Chan et al., 2007). However, in my study, I suggested task impairment in high neurotics is because of higher task demand on CES functions that is impaired by detrimental effect of neuroticism. In this view, worry and arousal increase task irrelevant activities and it interferes with attention thus task processing impairs (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). Therefore, because stimuli that I used are not emotional, the results replicate my statement. I discuss results regarding response times and error rates separately below.

Current results replicated the findings reported in experiment two (chapter 3) in terms of reaction times of high and low neurotics on PRP effect and dual task combination costs; (single/dual task) and (short/long SOA). Thus the results can be concluded that dual task cost differences between high and low neurotics are not attributable to emotional stimuli in the task. Also, replication of the previous results with different sample and different stimuli confirmed that high neurotics were slower than low neurotics on dual task processing (demand CES) as compared to single tasks (virtually no CES demand). This result indicates detrimental effect of neuroticism impairs CES functions in high neurotics as comparing low neurotics during task processing (Derakshan & Eysenck, 2009). Further, high neurotics had greater PRP effect than low neurotics. This may indicate high neurotics may encounter higher level of interference during bottleneck processing. High neurotics were observed with a considerable higher dual task cost on processing short SOA dual tasks than long SOA task as comparing low neurotics. These results indicate that when dual task restricted by SOA that makes the task more stressful and difficult, high neurotics considerably slowed down as compared to low neurotics on processing of dual task. Altogether, these results are same as the results reported in chapter 3. This means that task impairment in high neurotics is caused by higher demand on CES functions and it is not associated with a possible effect emotional cue in the previous tasks.

Regarding overall error rates, although high and low neurotics did not reach significant results, low neurotics made higher errors than high neurotics. Such results are often explained by speed accuracy trade-off strategy in theoretical and empirical studies. It has been suggested high neurotics may focus one aspect of the experiment to accomplish the task (Flehmig et al., 2010) (see section 1.5.1). The reason for that is high neurotics use a speed accuracy criterion that focus accuracy while ignoring response times (Flehmig et al., 2010). Easterbrook's (1959) suggested that high level of neuroticism may leads people to narrow their attention during a dual task processing. They narrow their attention either on accuracy or response times (Easterbrook, 1959; M. W. Eysenck et al., 2007). In such case, high neurotics some times are quite slower but with higher accuracy (Flehmig et al., 2010). However, this is usually not enough for a higher processing efficiency in demanding cognitive tasks regarding high neurotics (M. W. Eysenck et al., 2007). In the current results, I observed that low neurotics had higher error rates than high neurotics; however the results were not strong enough to differentiate high and low neurotics. Relying on the theoretical view, high neurotics may use a different speed accuracy criterion and rather focus on task accuracy (Flehmig et al., 2010). Because, task irrelevant activities considerably interfere with attention during processing of cognitive resources, focusing on accuracy did not help to be significantly better than low neurotics (Derakshan & Eysenck, 2009).

It has been indicated that task processing is automatically set in the bottleneck mechanism in dual task processing (De Jong, 1993; De Jong, 1995b; Luria & Meiran, 2003). Accordingly, in fixed dual task processing, when first task comes the second task is automatically sat for processing (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005). Because participants performed fixed dual tasks only in this study, high neurotics may get a slight benefit of that automaticity by using speed and accuracy criterion. One strong evidence comes from previous dual task results (chapter 3); because the current results regarding error rates are similar as the previous results. In chapter 3, when demand on CES is maximized by random tasks, high neurotics were worse than low neurotics in error rates as well as in response times because advantage of setting tasks automatically were removed. Therefore, because task become very difficult for high neurotics, cognitive resources in high neurotics entirely consumed thus they were worse in response times and error rates.

This study is the key to the support of previous results because this replication involves the process of repeating the previous dual task study by using the same methods, with different subjects, and modified experimental design. For example, the study took place in Dicle University (Turkey) with a new and larger sample. Therefore, is important for some reasons, such as including assurance that results are valid and reliable, generalizability of task impairment in high neurotics in relation to CES demand. Further, it helps to guide for direction of next study by combining previous and current results.

In conclusion, I found high neurotics had greater impairment as task demand increase from single task to dual task and from long SOA dual tasks to short SOA dual tasks. The results replicate the previous dual task study that assures the results are valid and reliable. Thus, the results showed that task impairment is because of higher CES demand but not any effect of emotional stimuli in this study. In the next study, I increase task demand on CES functions by S-R mapping manipulation. Further, I explore detrimental effect of neuroticism in relation to CES and non-CES demand. Finally, I investigate perceptual task difficulty in high and low neurotics.

5 Chapter - Neuroticism related differences during processing of Dual task: Task set maintenance

5.1 Introduction

Response selection is defined as a decisional stage for execution of a proper reaction (Szmalec et al., 2005). Based on this point of view, response selection is found to be associated with the CES but not the WM storage systems (Allain et al., 2004; Bunge et al., 2000; Hegarty, Shah, & Miyake, 2000; Szmalec et al., 2005). In dual tasks, the components of the tasks set are supposed to include response selections, which are stimulus-response mappings, task rules, as well as the content of the task. These features of the tasks set are called task set maintenance (Stelzel et al., 2008a) and they have to be processed by the CES functions in the online state of working memory (Miller, 2000; Cowan, 1999; Logan & Gordon, 2001; Meiran, 1996; Rogers & Monsell, 1995). As discussed previously, the locus of the bottleneck is response selection and performing two choices in reaction tasks concurrently requires extensive use of the three main functions (switching, inhibition and updating) during this stage (De Jong, 1995; Logan & Gordon, 2001; Luria & Meiran, 2003; Meyer & Kieras, 1997; Szameitat et al., 2016). Accordingly, inhibition is required to avoid processing the second task until the first task has been processed in the bottleneck and switching is needed to shift the focus of the bottleneck from the first task to the second task (De Jong, 1993; De Jong, 1995b; Luria & Meiran, 2003). Also, updating is involved in maintaining the first and second task related contexts and rules until both tasks have been processed (De Jong, 1995a; Logan & Gordon, 2001). According to Szamelec et al., (2005) increasing stimuli response mapping is mainly associated with three main functions in the response selection stage because the response selection stage is a decisional stage for execution of a proper reaction. In this context, increasing stimuli response (S-R) mappings (S-R load) places a higher demand on the three main functions of the CES. In other words, two choice dual task processing is associated with switching, inhibition and updating. If the task involves three or four choices then the number of items that should be switched, inhibited and updated increases considerably. Consequently, a higher dual task cost occurs during the task processing because of the higher demand on these functions. For example, Szamelec et al., (2005) explored the effect of S-R load in dual tasks (see section 1.5.2.). One condition in the study included fixed dual tasks with a manipulated set size from two to four choice S-R mappings. In the dual tasks, the participants were required to respond to one of four digits presented in the centre of the screen by pressing either one of four (4-choice tasks) or two buttons (2-choice tasks) on the keyboard. The authors found that increasing the S-R load in a dual task dramatically increases the dual task cost. In chapters 3 and 4, I showed that the higher dual task cost in high neurotics compared to low neurotics is due to an impairment of the switching, inhibition and updating functions. Relying on this information, this study is designed to investigate the effect of the S-R load placed on the central executive system in high and low neurotics during the cognitive processing of dual tasks. The task demand is increased by S-R loading manipulation across the experiment. Thus, the task demand increases from a one choice single task to two, three and four choice reaction dual tasks. Increased demand on task set maintenance due to a larger task set size in dual tasks may be a factor that causes additional cost in high neurotics during cognitive processing of the dual task.

Note that because the single task was not a dual task and required virtually no CES functions, I assess this task separately in the results. I use it to derive dual task combination costs and I aim to show that there was no difference between the high and low neurotics in the single task processing as the easiest condition. Therefore, the single tasks were always identical and required one response for each trial.

Contrary to the previous experimental design (Visual-Auditory and Auditory-Visual), in the present study, the presentation of the tasks is included one type of task order which is Visual-Auditory so that memory load increased in visual task only. In other words, in this experiment, the S-R load, which means the demand in response selection (demand CES), was increased from two to three and four choices in the visual tasks whilst the auditory tasks remained as two choices as in the previous tasks. The reason for that is that the VSSP is not involved in task impairment whereas the phonological loop (PL) storage may be partly involved at some points (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). The common point between PL and worry supposed to be that both are associated with inner words that may contribute to task irrelevant activities (M. W. Eysenck et al., 2007). Therefore, if PL is demanding, it may contribute to task irrelevant activities in high neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). I also confirmed in the first empirical study that even though the load increased in the VSSP, no differences were found between the high and low neurotics (see section 2.3). Therefore, any higher cost in the high neurotics compared with the low neurotics in the S-R loading manipulation will be because of demand on the CES functions.

In addition to stimuli response mapping manipulation, the task demand was increased by SOA manipulation as well. Previously, I showed that SOA manipulation increases the demand on the CES functions and thus the high neurotics had higher dual task costs as the SOA decreased (for short and long SOA see section 1.3.2 and 3.1.) (De Jong, 1995b; Luria & Meiran, 2005). Therefore, each condition presented either with a short or long SOA. In the long SOA task, the task demand was increased only by S-R loading manipulation from two to three and four choices. In the short SOA task, the task demand was increased both by SOA (SOA 0 ms) and S-R loading manipulation.

Taken together, the short SOA tasks with S-R loading manipulation were relatively the most difficult tasks because the task demand on the CES was increased by SOA and S-R loading manipulation. These tasks, which involved a four choice dual task with a short SOA, were the most difficult because the demand on the inhibition, switching and updating functions was maximized. On the other hand, the tasks with S-R loading manipulation a long SOA were only relatively moderately difficult because the task demand was increased by S-R loading manipulation and 1000 ms SOA was set. Thus, there was more time to prepare the processes for the CES functions (switching and inhibition functions) with the long SOA tasks.

PRP dual task studies have shown that task set maintenance (S-R mappings) and task coordination (called random task) are associated with the CES. However, there are different types of demand. In chapter 3, I found that the high neurotics had a greater dual task cost compared with the low neurotics. In particular, the dual task cost was much higher during the processing of the random order task in the high neurotics compared to the low neurotics. In the random order task the demand were increased on the three main functions (see section 1.5.1). Because random task processing involves re-arrangement of the task set for each trial, a higher demand was placed on the switching and inhibition functions (De Jong, 1995b; Luria & Meiran, 2003; Szameitat et al., 2016). However, when the demand was increased via S-R loading manipulation, it seemed that the demand on the updating function also dramatically increased (Allain et al., 2004; Stelzel et al., 2008a). In previous studies (chapter 3-4), S-R loading, task rules, as well as the content of the tasks have been updated for two choice tasks only. However, now, these features have been updated for three and four choice tasks. According to ACT, task set maintenance is one of the main functions of the central mechanism, which is called updating (Eysenck, et al, 2007). Although it is supposed that the updating function is involved in the repository storage of working memory as well, it is commonly accepted as one of the main functions of the central executive system because the updating function is supposed to be involved in refreshing, maintaining and monitoring mental representations during the processing of the tasks (Derakshan and Eysenck, 2009; Eysenck, et al, 2007, Miyake, et al, 2000, p. 56). Therefore, in addition to increasing the demand on the switching and inhibition functions, the demand on the updating function was also increased considerably in the present study.

Regarding neuroticism related differences, attentional control theory suggests that as soon as the load on the central executive system is increased, the processing efficiency will reduce (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). However, it is well known that working memory capacity is limited for everyone (Baddeley, 1996b; Baddeley, 2000; Engle, 2002). From this perspective, I expected an inverted U curve, as Eysenck (1967) suggested, if the task very easy, as both the high and low neurotics will perform similarly. Because high neurotics have a lower arousal level threshold, they have higher task impairment in a demanding task compared to low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; M. W. Eysenck, 1985). If the task becomes very difficult then the arousal level will exceed the threshold in high and low neurotics and thus cognitive resources will be consumed in the working memory capacity of both high and low neurotics. In this case, the differences regarding the dual task costs will be constant (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; M. W. Eysenck, 1985). Therefore, I expected the dual task cost to be greater in high neurotics as the task set increased to some extent. I formulated two hypotheses for my expectation: first, the dual task combination cost differences between the high and low neurotics will become larger as the load is increased by S-R loading manipulation in the long SOA tasks. Second, the dual task combination cost differences between the high and low neurotics do not become larger in the short SOA task as the load is increased by S-R loading manipulation. The reason for that is that the arousal level will exceed the activation threshold that causes task irrelevant activities in both the high and low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Therefore, limited cognitive resources would be consumed by higher task related and task irrelevant activities in both groups (Corr, 2003; M. W. Eysenck & Calvo, 1992; Sarason, 1988; Sarason et al., 1990).

In addition, the PRP effect is not a task; it is a variable that shows the interaction between the RT2 short SOA and RT2 long SOA task (Meyer & Kieras, 1997a; Pashler, 1993; Pashler, 1994b). Because the PRP effect indicates an additional delay RT2 in the short SOA compared to the long SOA (Meyer & Kieras, 1997a; Pashler, 1994b), I assessed this form of cost with the short SOA tasks. Therefore, these variables were assessed as one of the most difficult conditions in the short SOA tasks. The hypothesis to be tested is that PRP effect cost difference between the high and low neurotics do not become larger as the load was increased by S-R loading manipulation.

In the study, I also increased the task demand in perceptual stages by adding degraded stimuli in the visual task. Stimulus degradation in cognitive studies has been investigated previously in normal subjects (e.g., Barch et al., 1997) (see section 1.3.4.). It has been indicated that stimuli degradation increases the task difficulty but is disassociated from WM demand (Barch et al., 1997; Luria & Meiran, 2005). Furthermore, it has been found that stimuli degradation does not influence the response selection stage because it is associated with perceptual processes (Rubinstein, Meyer, & Evans, 2001). One reason for that is PRP bottleneck theories suggest that while perceptual and motor execution processes can handle both tasks in parallel, the response selection stage, which is the locus of the bottleneck process, can only handle one task at a time (Logan & Gordon, 2001; Meyer & Kieras, 1997b; Pashler, 1993; Pashler, 1994a). Moreover, I found that increasing the demand on the CES functions in bottleneck processes (response selection stage) causes a higher impairment in high neurotics (chapters 2-4). In this context, the detrimental effect of neuroticism impairs the CES functions, which are associated with the response selection stage, and then if the task demand increases at the other stages the high and low neurotics should not differ because the two tasks can be processed in parallel in the other stages. However, to date there is no study that has explored increasing task difficulty that is disassociated from working memory in relation to the detrimental effect of neuroticism. Therefore, one question of interest would be whether a higher dual task cost in high neurotics is due to an impairment in the processing of the bottleneck (the CES demand) or whether it is just because of any type of task difficulty apart from the demand placed on the CES. The hypothesis to be tested is that dual task combination cost differences between high and low neurotics do not become larger as the task difficulty is increased by stimuli degradation.

Finally, according to Eysenck (1967), high neurotics perceive higher stress and task difficulty than low neurotics in demanding task performance. In line with that, PET and ACT suggest that high neurotics will have higher scores regarding difficulty and stress level on the questionnaires after WM task performance (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). It has been suggested even though high and low neurotics may have similar cardiovascular activities, high neurotics may have higher perceived difficulty in demanding task performance because the higher sensitivity toward stressful conditions in high neurotics than low neurotics, (H. J. Eysenck, 1967; M. W. Eysenck et al., 2007). Note that in the theory, with regard to task difficulty, Eysenck (1967) does not specify whether it is CES demand or non-CES demand. Therefore, increasing any type of difficulty in a cognitive task may lead to higher perceptual stress and difficulty in high neurotics. I used a subjective measure that investigates perceived stress level by scoring the task stressfulness after completion of the experiment. In this part, the participants were required to score their perceived stress and difficulty level for each task just after the experiment was completed. Regarding subjective measures, I aimed to investigate the perceived stress level differences between high and low neurotics. The hypothesis to be tested is that the high neurotics will have higher perceived stress scores than the low neurotics as the demand increased in the tasks.

Altogether, first, I aimed at testing whether the impairment in dual task processing in high and low neurotics will increase as the S-R load increase. Second, I explored whether the greater dual task cost occurred due to the CES demand or whether any kind of task demand may cause such a cost. Third, I aimed at investigating the perceived stress level differences between the high and low neurotics. To do so, I formulated several hypotheses as follows:

I. The high and low neurotics will not significantly differ regarding processing efficiency in single tasks (general pattern as in previous single tasks).

II. The PRP effect cost differences between the high and low neurotics will not become considerably larger as the load increases, as is evident in similar processing efficiencies.

III. The dual task combination cost differences between the high and low neurotics should not be greater regarding RTs and error rates as the load increases in short SOA tasks (i.e. the differences between the high and low neurotics regarding processing efficiency will not be significantly larger as the load increases)

IV. The dual task combination cost differences between the high and low neurotics should considerably increase as the load increases both for RTs and error rates in long SOA tasks (i.e. lower processing efficiency as the load increases in high neurotics).

V. There should be no major dual task cost differences between the high and low neurotics regarding processing of degraded and non-degraded three choices dual tasks either in RTs or in error rates.

VI. The perceived stress level will be higher as the task demand is increased either by S-R mapping manipulation or stimuli degradation in high neurotics compared to low neurotics.

5.2 Methods

5.2.1 Participants

To create extreme groups of high and low neurotics (High-N and Low-N, respectively), I screened 300 participants using the 24-item neuroticism scale of the Eysenck Personality Questionnaire (EPQ; Eysenck and Eysenck, 1975). Three participants were excluded because of current or previous depression or anxiety disorders, according to the history of past or current psychiatric or neurologic disorders questionnaire. From the N screened people, 41 people took part in the final experiment: 21 (11 female) were in the High-N group (mean EPQ score=18, range=16–24) and 20 (10 female) in the Low-N group (mean EPQ score= 3.89, range=0–6). The two groups were matched for age (High-N = 21.36 and Low-N=23.50) and gender. All of the participants were right handed as assessed by the Edinburgh Inventory (Oldfield, 1971) and had normal or corrected to normal vision. Before participation each participant gave written informed consent. Participants were paid £10 for 1 hour of participation. The study was approved by the Department of Life Sciences ethics committee at Brunel University.

5.2.2 Exclusion criteria for selection of high and low neurotics

The exclusion criteria were identical to the experiments in chapters 1, 2, 3 and 4.

5.2.3 Tasks

The participants had to perform two choice single tasks. In the dual task conditions, the participants performed two, three and four choice visual tasks with two choice auditory tasks in separate blocks. Finally, they completed a perceived stress questionnaire regarding the task difficulty.

5.2.3.1 Single tasks

In the single tasks (visual and auditory single tasks), I used only two choice reaction tasks because I aimed to create the easiest conditions (H. J. Eysenck, 1967).

5.2.3.1.1 Visual single task (VIS).

In the visual single task, two digits, 1 and 2, were presented. The visual single task consisted of 75 trials divided into 3 blocks of 25 trials each. A trial in the VIS condition started with a blank grey screen for 300 ms, followed by a fixation period of 300 ms. Digits 1 and 2 were presented for 300 ms. Thus, the trial duration depended on the response speed of the participant. Then, either error feedback ("Error") or a fixation cross was displayed. The duration of this error feedback / fixation cross was 300 ms. Thus, the interval between the last response and the onset of the next stimulus (Response-Stimulus-Interval, RSI) was always 1300ms.

5.2.3.1.2 Auditory single-task (AUD)

The auditory condition consisted of beep tones with either low (400Hz) or high (700 Hz) pitches. The auditory single task (Beep tone task) consisted of 75 trials divided into 3 blocks of 25 each. A trial in the AUD condition started with the same blank screen and fixation period as in the visual single-task. The key mapping was X for the low beep tone and C for the high beep tone on the keyboard. The other characteristics of the auditory single task were identical to the visual single task.

5.2.3.2 Fixed order dual task

In contrast to the previous experiments, I employed a visual =>auditory task order only as the fixed dual task condition. The main reason for that is explained in the introduction. The other reason is because there was limited time to process all of the conditions. The dual task consisted of a visual and an auditory task. The response choices were manipulated in the visual task. There was two, three and four choice visual tasks conditions that included digits 1 & 2; 1, 2 & 3 and 1, 2, 3 & 4 respectively. The auditory task always remained identical as in the single task. Each visual condition was presented with auditory tasks in separate blocks.

The dual task conditions were presented with 0 and 1000 ms. SOA manipulations. Overall, the dual task conditions consisted of 200 trials divided into 2 blocks with 50 trials in each. The rest of the conditions regarding the timing in the stimuli presentation were identical to the experiments in chapters 3 and 4.

The dual task (digit => beep tone) with a short SOA (0 SOA) (non-degraded) consisted of 3 blocks with 50 trials in each that included the presentation of digits and a beep tone (digit => beep tone) simultaneously. The first fixed dual task condition consisted of a two choice reaction task that included two digits (1 and 2) as the visual task and high and low beep tones as the auditory task (the two tasks were identical as in the single tasks). The second fixed dual task consisted of a three choice visual reaction task that included the digits 1, 2 and 3; the auditory task remained identical to the first dual task condition, as a two choice auditory reaction task. The three choice visual tasks were presented in two forms: degraded and non-degraded while the auditory task was the same as before. The degraded three choice visual tasks were identical to the non-degraded three choice visual tasks except for the presentation of each digit because the digits were shielded by a virtual square in which 75% of the pixels were randomly degraded (see Figure 5.1.). In the three choice dual tasks, the key mapping for digits 1, 2, and 3 was respectively N, M, and coma (,) on the keyboard. The key mapping for the auditory task was the same as in the single tasks (low beep tone: X and high beep tone: C). Finally, the fourth fixed dual task condition consisted of a four choice visual reaction task that included the digits 1, 2, 3 and 4; the auditory task remained identical to the previous tasks. All of the conditions of the dual task with a long SOA were identical to the dual task with a short SOA except for 1000 SOA between the presentations of the stimulus because the digits were presented at first and after 1000ms SOA a beep tone was presented. The key mapping for digits 1, 2, 3 and 4 was respectively N, M, coma (,) and full stop (.) on the keyboard. The key mapping for the auditory task was the same as in the single tasks (low beep tone: X and high beep tone: C).

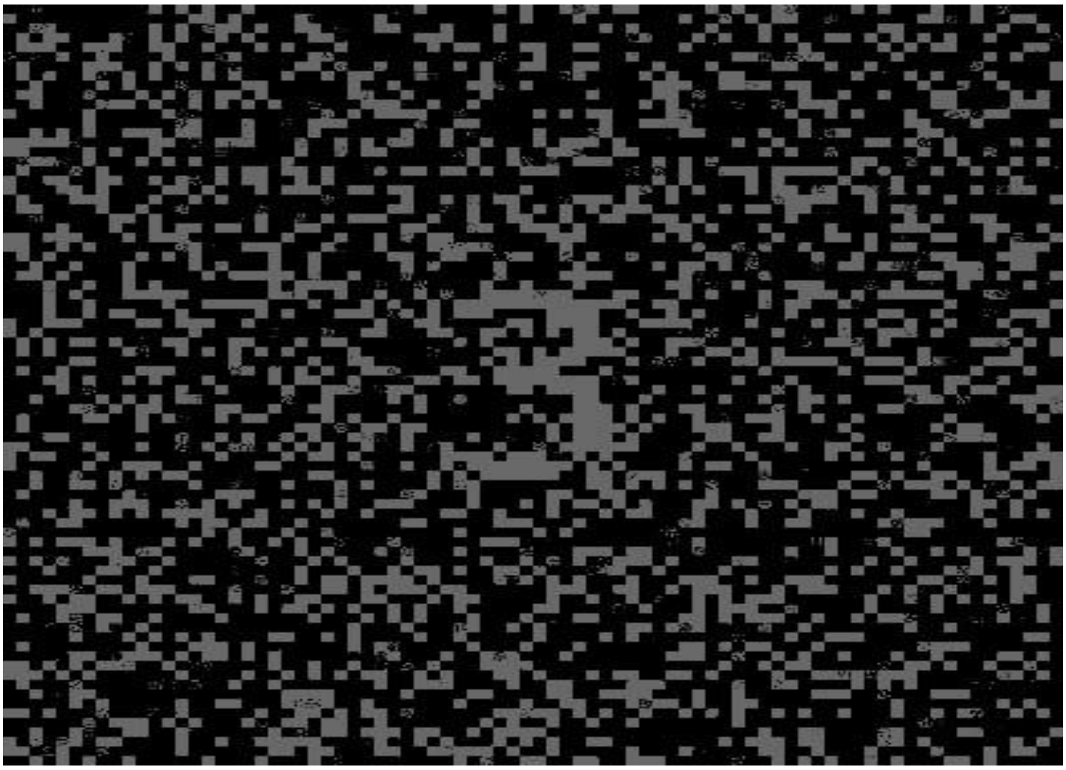

Figure 5-1 An example of the degraded stimuli presented in the three choice dual task conditions.

5.2.4 Perceived stress level questionnaire

In this experiment a subjective measure of perceived stress level was included. There were six items that asked the participants 'how stressful and difficult was the task?'. Each item had an identical scale from 1 (very easy) to 9 (very difficult). Overall, a score from 1 to 3 indicated that the task was easy; from 4 to 6 indicated that it was moderate; and 7 to 9 indicated that it was difficult.

5.2.4.1 Procedure

The first stage of the procedure was identical to the previous experiments (see experiments 2 and 3) including the screening procedure, exclusion criteria and questionnaires that had to be filled in by the participants.

After completion of the first stage, the dual task experiment started. While sitting on the chair in the cubicle room the participants performed a PRP dual task, consisting of two, three and four-choice visual, and two choice auditory tasks in separate blocks (Fig. 5.2 and 5.3.). Firstly, all of the participants performed all types of the single and dual tasks in the practice, which lasted for around 15 minutes.

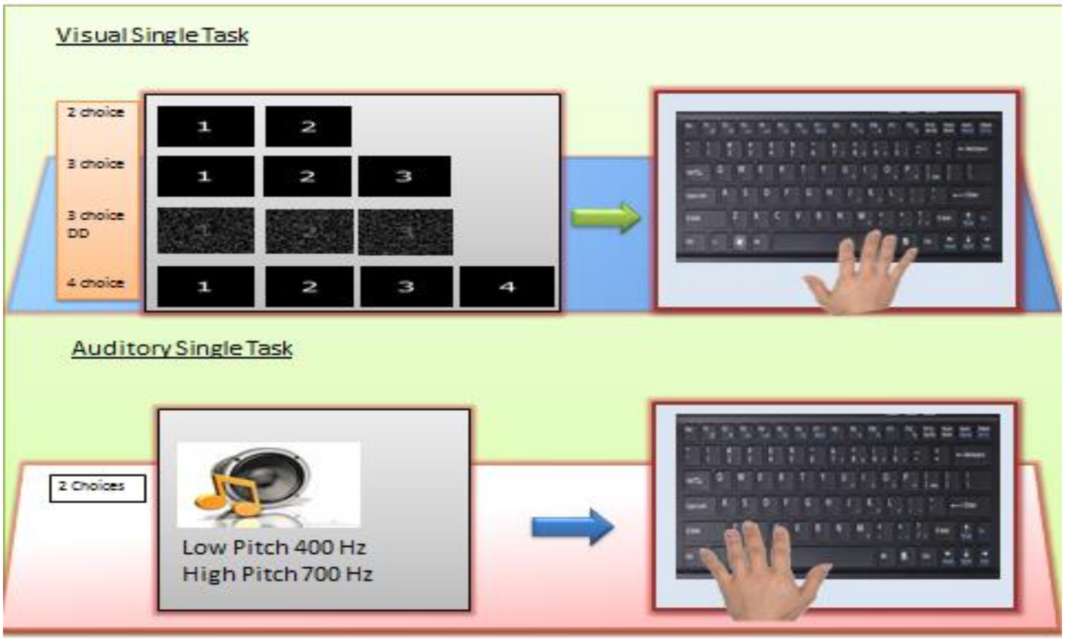

Figure 5-2 shows visual and auditory single task experimental design

Figure 5-3 Shows dual tasks experimental design along response mapping manipulation

In the single tasks, the participants were presented with the visual and auditory single tasks. A trial in the VIS condition started with a blank grey screen for 300 ms, followed by a fixation period of 300 ms. The digits were presented for 300 ms. The participants had to respond with the right index finger to the 1 by pressing the N button, and with the right middle finger to the 2 by pressing the M button on the keyboard for the two choice visual reaction tasks. Thus, the trial duration depended on the response speed of the participant.

Then, if their response was wrong, the participants saw error feedback ("Error") displayed on the screen. If their response was correct they saw a fixation cross.

The trial in the auditory condition was the same as in chapter 4. The condition started with an identical blank screen and fixation period as in the visual single-task. After the fixation period, a beep tone was presented for 300ms. In the auditory task, the participants had to respond to the high beep tone with their left index finger by pressing C and to the low beep tone with the left middle finger by pressing the X button on the keyboard. The other characteristics were the same as in the two choice visual tasks.

In the dual task condition, both the visual and auditory tasks were presented either simultaneously or in rapid succession, separated by the stimulus-onset-asynchrony (SOA). The two choice dual tasks consisted of visual and auditory single tasks. Thus, the response procedure for key mapping was the same as in single tasks for the two choice dual tasks. The procedure for the dual task conditions regarding the response order and auditory task was always the same as in the two choice dual tasks. However, in the visual task, the participants had to respond with the right index finger to the 1 by pressing the N button, with the right middle finger to the 2 by pressing the M button, and to the 3 with the ring finger by pressing the coma (,) button for the three choice visual reaction tasks. Furthermore, the participants had to respond with the right index finger to the 1 by pressing the N button, with the right middle finger to the 2 by pressing the M button, with the ring finger to the 3 by pressing the coma (,) button, and to the 4 with the little finger by pressing the full stop (.) button for the four choice visual reaction tasks. A special instruction about the upcoming choice dual task was given immediately before each block. In other words, before each task, they were told whether the task had 2, 3 or 4 choices and whether it was degraded or non-degraded. For example, if the task was a 3 choice dual task the instruction was '3 digits non-degraded'. The participants were instructed to respond to both tasks as fast and as accurately as possible. Furthermore, they were strongly encouraged to respond to both tasks in the order of presentation. This part of the instruction favoured the first over the second task during dual-task processing. To ensure equal trial duration under each SOA condition, the time available to respond to the second stimulus was adjusted depending on the SOA variations. For the long SOA tasks, to avoid 'grouping the stimuli' (stimuli grouping: after both stimuli presented and then they respond stimuli), the participants were required to respond to the digits and, after 1000ms SOA, to respond to the beep tone as quickly as possible.

Additionally, after completion of the experiment, the participants scored the stressfulness and difficulty of each task by marking it from 1 (very easy) to 9 (very difficult) on a paper sheet. For example, if the tasks were perceived as very easy the participant marked 1, 2 or 3 and if the task was moderately difficult then the participant marked it 4, 5 or 6. On the other hand if the task was very difficult, then the participants marked it 7, 8 or 9 for each task. At the end of the study all of the participants were given a debriefing form.
Overall the study took one hour for each participant to complete the study.

5.2.4.2 Data analysis

If not otherwise noted, in the following analyses, an independent t test or analysis of variance (ANOVA) mixed design was used. The significant effects for the ANOVA tests were reported at $p < .05$ unless otherwise stated. For the t test the significant effects were $p< .05$ two tailed. The between-subject independent variable was Neuroticism (High-N vs. Low-N). The within-subject variables were the different task conditions and these vary between the analyses. They will be described in the results section. The dependent variables were the response times and the error rates.

5.3 Results

5.3.1 Single Task

Descriptive Statistics					
Single Tasks	Groups	No	Mean	Std. Deviation	Std. Error Mean
Response times	HIGH N	21	477	55.79	12.17
	LOW N	20	457	65.66	14.68
Error rates	HIGH N	21	.049	.044	.009
	LOW N	20	.057	.038	.008

Table 5-1 Response times for participants with high levels of neuroticism (High-N,) and low levels of neuroticism (Low-N). Single Task is the average of both single tasks.

Independent t tests were performed to present the performance of the high and low neurotics on the single tasks regarding reaction times and error rates for testing first hypothesis (The high and low neurotics will not significantly differ regarding processing efficiency in single tasks (general pattern as in previous single tasks)). The results showed that although the high neurotics were numerically slower, the high and low neurotics did not differ significantly in terms of the reaction times in the single tasks [$t\ (41) = 1.35$; $p > .05$]. Regarding the error rates, the independent t test showed that although the low neurotics made more errors numerically, the high and low neurotics did not significantly differ regarding the error rates in the processing of the single tasks [t (41) = -.69; p >.05] (see table 5.1). Overall, the results indicate that the high neurotics and low neurotics were not differing regarding processing efficiency. The results confirm my first hypothesis that indeed high and low neurotics do not statistically and significantly differ regarding single task processing.

5.3.2 PRP Effect Regarding Response Mapping (S-R loading) Manipulation

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
PRP2ND	HIGH N	348	108	21
	LOW N	262	95	20
PRP3ND	HIGH N	356	100	21
	LOW N	287	101	20
PRP3DD	HIGH N	402	143	21
	LOW N	341	120	20
PRP4ND	HIGH N	440	191	21
	LOW N	417	125	20

Table 5-2 Response times of PRP effects for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). PRP Effect is derived by subtraction of long SOA dual-task response orders from Short SOA response orders (response times were taken from the second task).

In the analyses of the dual tasks, there are more variables than in other studies. Because I will use these variables frequently, I prefer to use abbreviations as follows: Dual task (0 SOA) two choices: DT02N; Dual task (0 SOA) three choices: DT03N; Dual task (0 SOA) four choices: DT04N; Dual task (0 SOA) three choices with degraded stimuli: DT03DD. The abbreviations for the long SOA tasks are identical to the short SOA tasks except for the duration of the SOA. For example, Dual task (1000 SOA) with two choices: DT10002N.

To test the second hypothesis (The PRP effect cost differences between the high and low neurotics will not become considerably larger as the load increases, as is evident in similar processing efficiencies), I performed a 2x3 factorial ANOVA with the within-subject factor PRP effect for the S-R loading manipulation (DT2N vs DT3N vs DT 4N) and the between subject factor group (High N vs Low N). Note that the PRP effect is derived by subtracting DT0 (RT2) from DT1000 (RT2) for each task: PRP 2N (RT2; DT02N – DT10002N); PRP 3N (RT2; DT03N-DT10003N) and PRP 4N (RT2; DT04N-DT10004N). The results show that on average the high neurotics had a greater PRP effect than the low neurotics [neuroticism main effect, $F (1, 40) = 4.13$; $p < .05$]. Furthermore, the PRP-effect for the S-R mapping manipulation was evident, as illustrated by the on average slower RTs in the short SOA compared to the long SOA [S-R loading with PRP main effect, $F (1, 40) = 17.15$; $p < .05$] in all of the tasks. This indicates that regardless of the group differences, the PRP effects were getting larger as the task load increased from 2 to 3 and 4 four S-R loads. However, the results demonstrate that manipulation of the S-R mapping regarding the PRP effects in high and low neurotics did not reach significance [S-R load X group interaction, $F (1, 40) = 1.04$; $p > .05$]. Contrast analyses along the S-R mapping regarding the PRP effects again show that the cost differences between the high and low neurotics did not significantly differ as the load increased: within subject factor PRP (DT2N vs DT4N) and between subject factor (high vs low) [$F (1, 40) = 1.75$; $p > .05$]; within subject factor PRP (DT2N vs DT3N) and between subject factor (high vs low) [$F (1, 40) = 1.37$; $p > .05$]. The results indicate that although the high neurotics had a greater cost in the form of a PRP effect in all tasks (see table 5.2.), as the load increased the differences between the groups in terms of the PRP effect did not reach a statistically significant level ($p>.05$) (see figures 5.4). Taken together, the results are in line with my second hypothesis, in that they show that the PRP cost differences between the high and low neurotics do not significantly became larger as the S-R load increase for both groups.

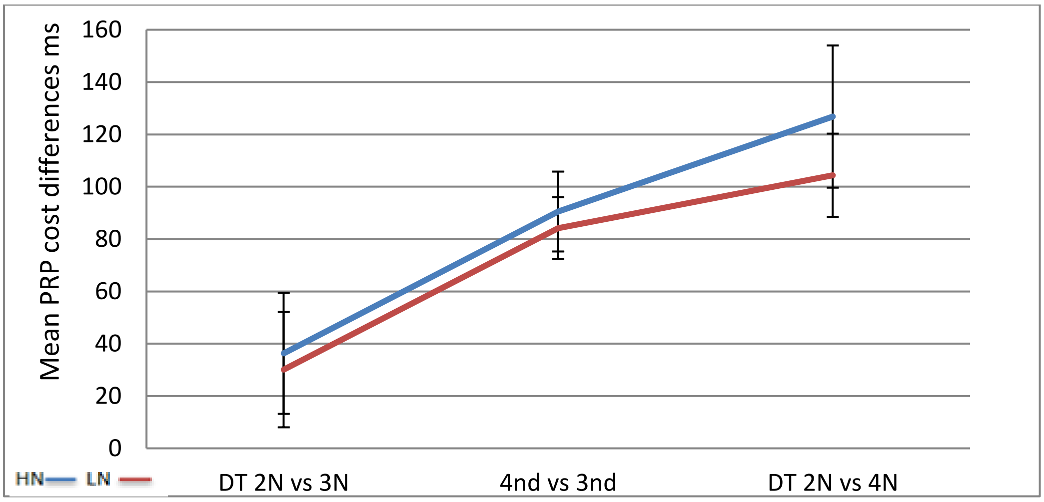

Figure 5-4 shows the interaction effects between the groups and S-R mapping manipulation. PRP effect is derived by subtracting the long SOA RT2 from the short SOA RT2 for each dual task along the S- R manipulation.

5.3.3 Effect of Stimuli and Response Mapping (S-R loading) Manipulation Regarding Dual Task Combination Costs

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
DT0 2ND RT1	HIGH N	710	149	21
	LOW N	620	94	20
DT0 3ND RT1	HIGH N	722	163	21
	LOW N	642	121	20
DT0 3DD RT1	HIGH N	815	184	21
	LOW N	691	100	20
DT0 4ND RT1	HIGH N	801	183	21
	LOW N	706	102	20
DT0 2ND RT2	HIGH N	1029	169	21
	LOW N	872	123	20
DT0 3ND RT2	HIGH N	1078	200	21
	LOW N	925	158	20
DT0 3DD RT2	HIGH N	1179	278	21
	LOW N	1006	123	20
DT0 4ND RT2	HIGH N	1206	259	21
	LOW N	1055	192	20

Table 5-3 Response times of short SOA for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Short SOA response times were presented from the first and second task (visual=>auditory) in the dual-task.

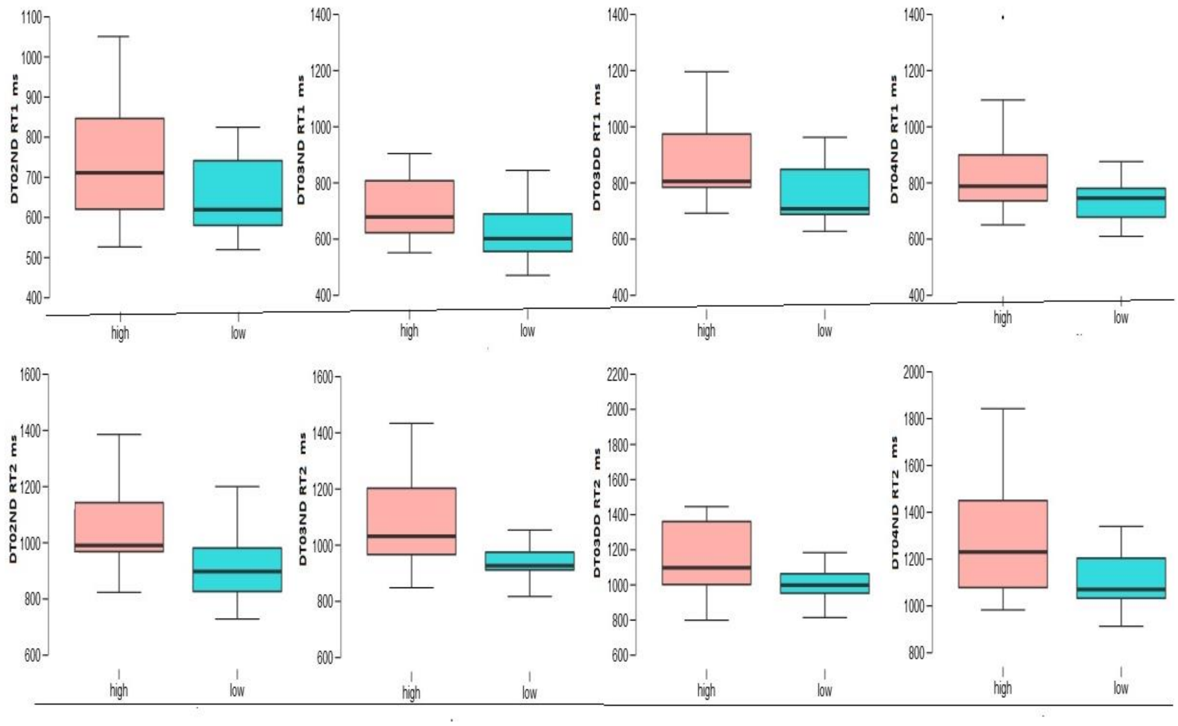

Figure 5-5 mean and SD of response time for each dual task condition in the form of boxplots for participants high (pink box) and low (blue box) in neuroticism level. Note that each result has been presented with a different scale

In this section, I presented the interaction effects between the dual task combination costs across the S-R loading manipulation and neuroticism levels. Regarding the dual task combination costs, I presented analyses of RT1 as well as RT2 because I increased the load in the first task. It is known that increasing the load in the first task influences task 1 as well as task 2 (Pashler, 1993; Pashler, 1994b). To examine the effect of neuroticism on the S-R load, I calculated a 2x3 factorial ANOVA along the dual task cost variables. To test the third hypothesis (The dual task combination cost differences between the high and low neurotics should not be greater regarding RTs and error rates as the load increases in short SOA tasks (i.e. the differences between the high and low neurotics regarding processing efficiency will not be significantly larger as the load increases)) for the RT1 with short SOA task; the within-subject factor was dual task combination costs across S-R loads (RT1; DT02N vs DT03N vs DT04N) and the between subject factor was groups (High N vs Low N). The results showed that on average the high neurotics were slower than the low neurotics [neuroticism main effect, $F(1, 40) = 4.39$; $p < .05$]. Furthermore, the cost in RT1 was evident, as illustrated by the on average slower RTs as the S-R loads increased in the short SOA [S-R mapping (short SOA) main effect, $F(1, 40) = 22.47$; $p < .05$]. However, the dual task combination cost differences between the high and low neurotics did not become larger as the demand increased along the S-R loading manipulation (RT1), as is evident from the non-significant interaction between the groups and RT1 S-R manipulation [$F (1, 40) = .12$; $p > .05$].

Similarly, to test the third hypothesis for RTs2, I calculated the same analysis for RT 2 with a short SOA; the within-subject factor was dual task combination costs along S-R loads (RT2; DT02N vs DT03N vs DT04N) and the between subject factor was groups (High N vs Low N). The results showed that on average the high neurotics were slower than the low neurotics [neuroticism main effect, $F (1, 40) = 5.34$; $p < .05$]. Furthermore, the cost in RT2 was evident, as illustrated by the on average slower RTs in the short SOA as the task load increased [S-R loading (short SOA) main effect, $F (1, 40) = 45.75$; $p < .05$]. However, the dual task combination cost (RT2) differences between the high and low neurotics did not become larger as the demand increased along the S-R loading manipulation, as is evident from the non-significant interaction between the group and S-R mapping manipulation [$F (1, 40) = .01$; $p > .05$].

These results indicate that although the high neurotics had a greater dual task combination cost in DT02N, DT03N and DT04N, the cost differences between the high and low neurotics did not become larger as the load was increased by S-R loading manipulation during the short SOA in RT1 and RT2 (see table 5.3). Taken together, these results confirm my third hypothesis and show that indeed the dual task combination cost differences between the high and low neurotics did not become greater as the load increased.

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
DT1000 2ND RT1	HIGH N	667	285	21
	LOW N	591	231	20
DT1000 3ND RT1	HIGH N	732	323	21
	LOW N	607	199	20
DT1000 3DD RT1	HIGH N	841	365	21
	LOW N	681	231	20
DT1000 4ND RT1	HIGH N	832	325	21
	LOW N	642	134	20
DT1000 2ND RT2	HIGH N	681	186	21
	LOW N	609	118	20
DT1000 3ND RT2	HIGH N	722	184	21
	LOW N	637	131	20
DT1000 3DD RT2	HIGH N	776	253	21
	LOW N	665	146	20
DT1000 4ND RT2	HIGH N	766	213	21
	LOW N	637	108	20

Table 5-4 Response times of long SOA for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Long SOA is the average of both 1000 SOA dual-task response orders (response times were presented from the first and second task visual/auditory in the dual-task).

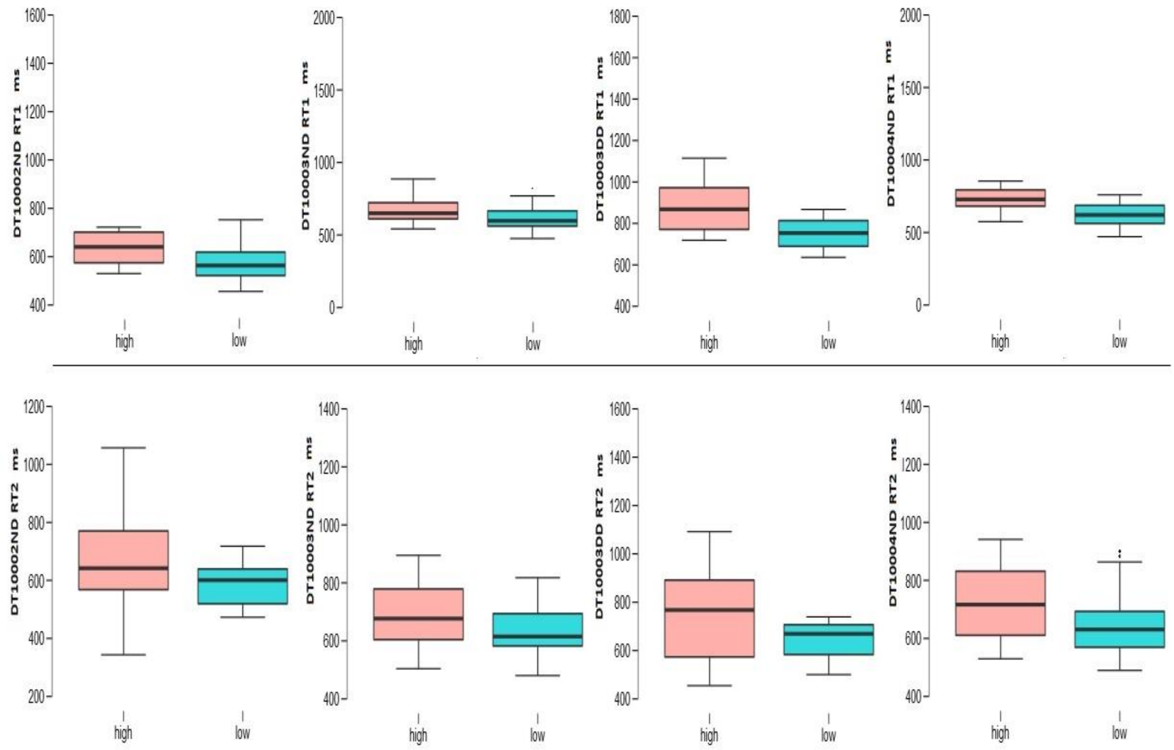

Figure 5-6 shows mean and SD of dula task long SOA response times (RT1 and RT2) in the form of boxplots for participants with high (pink box) and low (blue box) neuroticism level. Note that each result has been presented with a different scale.

To test the fourth hypothesis (The dual task combination cost differences between the high and low neurotics should considerably increase as the load increases both for RTs and error rates in long SOA tasks (i.e. lower processing efficiency as the load increases in high neurotics)) regarding RT1 with long SOA, I performed the same analysis for dual tasks with long SOA as well: the within-subject factor was dual task combination costs for S-R loads (RT1; DT10002N vs DT10003N vs DT10004N) and the between subject factor group (High N vs Low N). The analysis of dual the task combination cost with a long SOA revealed that the high neurotics were numerically slower than the low neurotics, although this result did not reach statistical significance [neuroticism main effect, $F(1, 40) = 2.07$; $p > .05$ ($p= .15$)] (see table 5.4). Furthermore, the cost in RT1 was evident, as illustrated by the on average slower RTs as the task load increased in the long SOA [S-R loading (long SOA) main effect, $F(1, 40) = 13.35$; $p < .05$]. Finally, in contrast to the short SOA results, the dual task combination cost (RT1) along the S-R mapping manipulation was larger for the high neurotics than for the low neurotics as the load increased, as is evident from the interaction between the groups and S-R loading manipulation [$F(1, 40) = 4.16$; $p < .05$]. Contrast analyses show that increasing the load was a significant moderator on the high and low neurotics when the load increased from (2nd vs 4nd) and (3nd vs 4nd) as is evident from the significant interaction for the within subject task S-R loading manipulation (2nd vs 4nd) and the between subject (High N vs Low N) [F (1, 40) = 6.76; p < .05] and within subject task S-R loading manipulation (3nd vs 4nd) and between subject (High N vs Low N) [F (1, 40) = 4.94; p < .05]. The significant interaction shows that indeed the cost differences of RT1 between the high and low neurotics as the load increased were evident from the slower RTs in the high neurotics compared to the low neurotics as the load increased in the form of dual task combination costs (see figure 5.5, panel A).

To test fourth hypothesis regarding RT2 with long SOA, , a 2x3 Anova was performed: the within-subject factor was dual task cost (RT2; DT10002N vs DT10003N vs DT10004N) and the between subject factor was groups (High N vs Low N). A comparable analysis of the dual task cost with a long SOA revealed the same general pattern of the results (RT1 long SOA) i.e. that high neurotics are slower than low neurotics [neuroticism main effect, F (1, 40) = 3.75; p< .05] (see table 5.4). Furthermore, the cost in RT2 was evident, as illustrated by the on average slower RTs as the task load increased with a long SOA [S-R loading (long SOA) main effect, F (1, 40) = 12.11; p < .05]. Finally, the dual task cost (RT2) along the S-R loading manipulation was larger for the high neurotics than for the low neurotics as the load increased, as is evident from the interaction between the groups and S-R loading manipulation [F (1, 40) = 3.42; p < .05]. Up close the results from the contrast analyses show that the cost differences between the high and low neurotics became larger when the load increased from DT10002N to DT10004N and DT10003N to DT10004N. The cost differences in RT2 were evident regarding the differences in the high and low neurotics, as illustrated by the interaction effects: within subject S-R loading (DT10002N vs DT10004N) and between subject (High N vs Low N) [F (1, 38) = 5.10; p < .05] and within subject S-R loading (3nd vs 4nd) and between subject (High N vs Low N) [F (1, 40) = 4.92; p < .05] (see figure 5.5. panel B).

Taken together, the significant interaction confirms my fourth hypothesis and shows that the dual task combination cost differences between the groups considerably increased as the S-R mapping increased, as is evident from the slower RTs in the high neurotics than in the low neurotics.

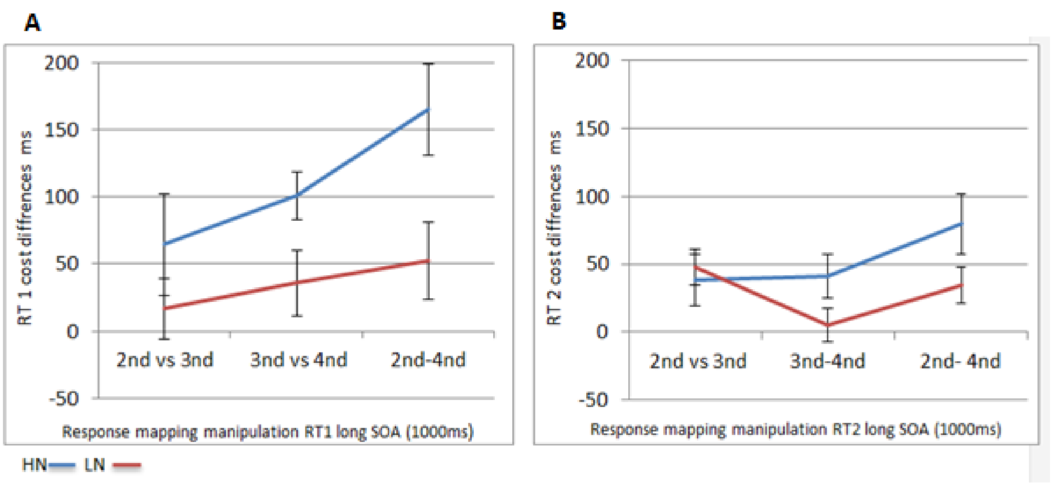

Figure 5-7 dual task cost is derived by subtracting single tasks from dual tasks. Thus the dual task cost is created for RT1 and RT2 respectively. In both panels the differences between the dual task costs from 2 to 3; 3 to 4 and 2 to 4 are compared to present the interactions between the group and SR mapping manipulation. Panel A shows the interaction effects between the group and S-R mapping manipulation for RT 1. Panel B shows the interaction effects between the group and response mapping manipulation for RT 2.

Overall, these results indicate that when SOA was ‘0’ the increased load in the working memory influenced both groups to a similar degree. Both the high and low neurotics took a longer time to complete the tasks and the high neurotics were always worse than the low neurotics along the tasks. However, the differences between the high and low neurotics regarding their reaction times remained below the significance threshold. On the other hand, when the SOA was set to 1000 ms, the increased load in task 1 and task 2 affected the high neurotics more significantly. Therefore, the dual task combination cost differences between high and low neurotics became higher as the load was increased by S-R loading manipulation.

5.3.4 Effect of stimuli degradation regarding PRP effect and combination of dual task costs

To examine the effect of stimuli degradation on neuroticism regarding PRP effects (fifth hypothesis), I calculated a 2x2 Anova: within subject factor PRP Effect (3nd vs 3dd) and between subject factors neuroticism (High N vs Low N). The results showed that on average the high neurotics had a greater PRP effect than the low neurotics [neuroticism main effect, $F(1, 40) = 4.16$; $p < .05$] (see table 5.2). Furthermore, a PRP-effect was evident, as illustrated by the on average slower RTs in the short SOA compared to the long SOA [SOA main effect, F (1, 40) = 7.46; p < .05]. However, the differences regarding the PRP-effects between high and low neurotics were similar along the degraded and non-degraded tasks, as is evident from the interaction between the groups and PRP effects [F (1, 40) = .04; p > .05].

To examine the effect of neuroticism on stimuli degradation in the RT1, similarly I calculated a 2x2 Anova: within subject factor RT1 short SOA (3nd vs 3dd) and between subject factors Neuroticism (High N vs Low N). The results showed that on average the high neurotics were slower than the low neurotics [neuroticism main effect, F (1, 40) = 3.29; p = .07]. Furthermore, the cost in RT1 for the degraded task was evident, as is illustrated by the on average slower RTs in the degraded task RT1 compared to the non-degraded task RT1 [degradation with a short SOA main effect, F (1, 40) = 13.73; p <.05]. However, the dual task cost differences (RT1) between high and low neurotics were similar on both tasks, as is evident from the non-significant interaction between the groups and SOA [F (1, 40) = 1.20; p > .05] (see figure 5.6. Panel A). Similarly, the analyses of RT2 with a short SOA regarding the degraded versus non-degraded dual task cost revealed the same pattern of results (neuroticism main effect: [F (1, 40) = 5.55; p < .05]; [degradation with short SOA main effect, F (1, 39) = 14.04; p < .05]; interaction: [F (1, 40) = .17; p > .05]) (see figure 5.6. Panel B). The same analyses were performed for the long SOA tasks. RT1 (neuroticism main effect: [F (1, 40) = 2.33; p > .05]; [degradation with long SOA main effect, F (1, 40) = 6.60; p < .05]; interaction: [F (1, 40) = .50; p > .05]) (see figure 5.6. Panel A) and RT2 (neuroticism main effect: [F (1, 40) = .10; p > .05]; [degradation with long SOA main effect, F (1, 40) = 2.76; p > .05]; [interaction, F (1, 40) = .54; p > .05]) (see figure 5.6. Panel B). These results regarding the task difficulty indicate that increasing the difficulty (degrading effect) in the perceptual stage influenced both the high and low neurotics to approximately the same degree and thus both groups took a longer time to complete the tasks. However, the task difficulty did not influence the differences in dual task costs between the high and low neurotics.

Taken together, the results indicate that increasing the difficulty (degrading effect) in the perceptual stage influenced both the high and low neurotics to the same degree and thus both groups took a greater PRP effect and dual task combination costs to complete the tasks. However, this did not influence the bottleneck processing differently in the high and low neurotics. Therefore, the non-significant interaction confirms my fifth hypothesis and shows that indeed neuroticism is not a considerable moderator on task difficulty at the perceptual level (see figure 5.6).

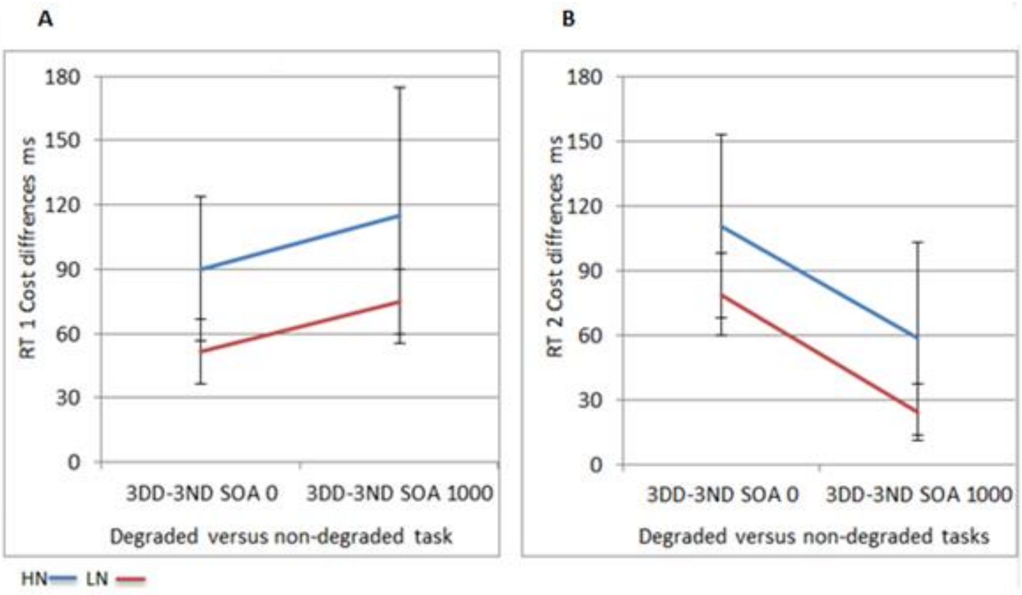

Figure 5-8 the dual task cost is derived by subtracting the single tasks from the dual tasks 3nd and 3dd separately, and thus the dual task cost is created for RT1 and RT2 respectively. In both panels the difference between the dual task costs from 3dd to 3nd for the short and long SOA tasks is compared to present the interactions between the groups and degradation effect. Panel A shows the interaction effects between the groups and degraded stimuli manipulation for RT 1. Panel B shows the interaction effects between the groups and degraded stimuli manipulation for RT2.

5.3.5 Error rates in dual tasks

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
DT0 2ND RT1	High N	.025	.029	21
	Low N	.031	.030	20
DT0 3ND RT1	High N	.011	.015	21
	Low N	.030	.029	20
DT0 3DD RT1	High N	.091	.155	21
	Low N	.037	.081	20
DT0 4ND RT1	High N	.038	.036	21
	Low N	.053	.079	20
DT0 2ND RT2	High N	.088	.080	21
	Low N	.100	.057	20
DT0 3ND RT2	High N	.080	.104	21
	Low N	.101	.086	20

DT0 3DD RT2	High N	.128	.128	21
	Low N	.092	.062	20
DT0 4ND RT2	High N	.108	.099	21
	Low N	.121	.087	20
DT1000 2ND RT1	High N	.038	.054	21
	Low N	.022	.029	20
DT1000 3ND RT1	High N	.021	.026	21
	Low N	.028	.025	20
DT1000 3DD RT1	High N	.131	.192	21
	Low N	.042	.062	20
DT1000 4ND RT1	High N	.049	.032	21
	Low N	.032	.023	20
DT1000 2ND RT2	High N	.105	.133	21
	Low N	.091	.078	20
DT1000 3ND RT2	High N	.132	.134	21
	Low N	.079	.081	20
DT1000 3DD RT2	High N	.082	.082	21
	Low N	.073	.061	20
DT1000 4ND RT2	High N	.120	.110	21
	Low N	.081	.061	20

Table 5-5 Error rates of short SOA and long SOA for participants with high levels of neuroticism (High-N) and low levels of neuroticism (Low-N). Response times were taken from the first and second tasks in the dual-task.

I performed a 2x3 ANOVA to examine the error rates along the dual task variables: the within subject error rates for S-R loads in the short SOA tasks (first task) (DT02N vs DT03N vs DT04N) and between the groups (High N vs Low N). The analysis of the error rates did not always reach statistical significance [neuroticism main effect, $F (1, 40) = .06; p > .05$]; [S-R mapping (short SOA) main effect, $F (1, 40) = 4.97; p <.05$]; interaction: [$F (1, 40) = .46; p > .05$]). The results showed that the high and low neurotics did not significantly differ as the load increased across the tasks. The same pattern of results was found for the short SOA (second task) (DT02N vs DT03N vs DT04N) and between the groups (High N vs Low N) [neuroticism main effect, $F (1, 40) = 1.87; p > .05$]; [S-R mapping (short SOA) main effect, $F (1, 40) = 5.34; p <.05$]; interaction: [$F (2, 78) = .35; p > .05$]). Taken together, regarding the error rates, in line with my third hypothesis, the results showed that the high and low neurotics did not significantly differ as the load increased across the tasks (see table 5.5).

A comparison of the error rates in the first task long SOA with the analyses of the RTs in the dual task combination costs revealed the same general pattern of results, which, however, did not always reach statistical significance [neuroticism main effect, $F (1, 40) = 1.41$; $p > .05$]; [S-R mapping (long SOA) main effect, $F (1, 40) = 4.59$; $p <.05$]; interaction: [$F (1, 40) = 2.27$; $p > .05$ ($p= .12$)]). The same pattern of results was found for the long SOA second tasks as well [neuroticism main effect, $F (1, 40) = .50$; $p > .05$]; [S-R mapping (long SOA) main effect, $F (1, 40) = 4.59$; $p <.05$]; interaction: [$F (1, 40) = 2.35$; $p > .05$ ($p= .12$)]). Taken together, although the results were not significant, the high neurotics always made more errors than the low neurotics, which supports my fourth hypothesis (see table 5.5).

Regarding the error rates in the degraded and non-degraded tasks in short SOA tasks, I performed a 2x2 Anova: the within subject factor was error rates in the dual tasks (DT03N vs DT03DD) and between the groups was (High N vs Low N). The results showed that the high and low neurotics did not differ regarding the error rates [neuroticism main effect, $F (1, 40) = .14$; $p > .05$]; [degradation (short SOA) main effect, $F (1, 40) = 3.28$; $p <.05$]; interaction: [$F (1, 40) = .17$; $p > .05$]) (see table 5.6). Regarding the error rates in the long SOA the results were not significant: the within subject error rates in the dual tasks (DT10003N vs DT10003DD) and between the groups (High N vs Low N) [neuroticism main effect, $F (1, 40) = 2.59$; $p > .05$]; [degradation (long SOA) main effect, $F (1, 40) = 1.27$; $p >.05$]; interaction: [$F (2, 78) = .57$; $p > .05$]). The results support my fifth hypothesis and thus show that the error rates differences between the high and low neurotics did not become larger as the task difficulty was increased by the degradation effect.

5.3.6 Perceived Stress level regarding high and low neurotic participants

Descriptive Statistics				
	Groups	Mean	Std. Deviation	N
ST	High N	1.73	1.03	21
	Low N	1.38	.63	20

DT 2ND	High N	4.23	1.22	21
	Low N	3.31	.77	20
DT 3DD	High N	5.38	1.46	21
	Low N	4.09	1.15	20
DT 3ND	High N	6.90	1.75	21
	Low N	5.00	1.63	20
DT 4ND	High N	6.6667	1.65	21
	Low N	5.4545	1.59	20

Table 5-6 shows average score for perceived stress level for High N and Low N participants along dual tasks.

Independent t test analyses showed no differences between the high and low neurotics in terms of their perceived stress level during the processing of the single tasks $p > .05$.

To examine the effect of perceived stress level along the single and dual tasks (sixth hypothesis), I performed a 2x3 Anova: the within subject perceived stress score for S-R manipulation (DT2N vs DT3N vs DT4N) and between the groups (High N vs Low N). The results showed that on average the high neurotics perceived a greater stress level than the low neurotics [neuroticism main effect, $F(1, 40) = 12.01$; $p < .05$] (see table 5.6). Furthermore, perceived stress level was a strong moderator in the dual tasks, as illustrated by the on average higher perceived stress in the dual tasks as the task load increased [perceived stress level, $F(1, 40) = 84.02$; $p < .05$]. Finally, the perceived stress level along the S-R loading manipulation was higher for the high neurotics than for the low neurotics as the load increased, as is evident from the interaction between the groups and the perceived level along the response loading manipulation [$F(1, 40) = 3.24$; $p < .05$]. The significant interaction confirms my sixth hypothesis and shows that indeed the high neurotics perceived a higher stress level than the low neurotics as the load increased, whereas both the high and low neurotics had approximately the same stress level in the single tasks (see figure 5.7).

I also explored the effect of stimuli degradation in relation to perceived task difficulty by performing a 2x2 Anova: the within subject perceived stress score (dt3nd vs dt3dd) and between the groups (High N vs Low N). The results showed that on average the high neurotics perceived the task more stressful and difficult than low neurotics [neuroticism main effect, $F(1, 40) = 13.96$; $p < .05$] (see table 5.6 and figure 5.7). Furthermore, perceived stress level was a strong moderator on the effect of degradation, as illustrated by the on average higher perceived stress in the degraded dual tasks as the task load increased [degradation main effect, $F(1, 40) = 84.02$; $p < .05$]. Finally, the high neurotics perceived a greater stress level and difficulty than the low neurotics as the load was increased by S-R loads, as illustrated by the interaction between the groups and the perceived level along the degraded versus non-degraded tasks [$F(1, 40) = 3.23$; $p < .05$]. This result indicates that the task difficulty was higher in all of the participants and the high neurotics perceived higher stress than the low neurotics in the degraded tasks.

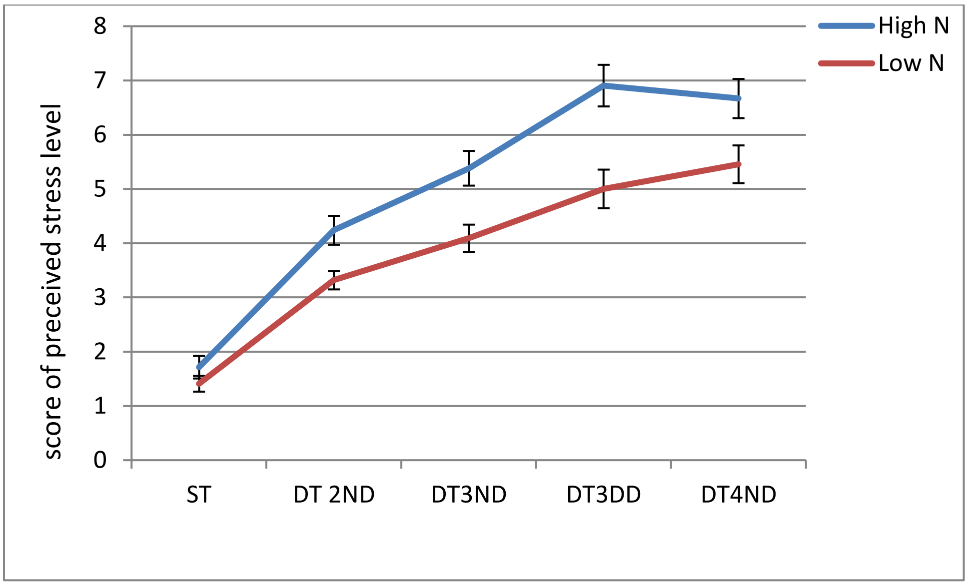

Figure 5-9 shows perceived stress level scores in high and low neurotics along the S-R mapping manipulation

5.4 Discussion

The results showed that the high and low neurotics did not differ regarding processing efficiency in the single task processing. Furthermore, the results demonstrated that the high neurotics had lower processing efficiency than the low neurotics in all of the dual tasks, as is evident from their slower RTs and higher error rates. The PRP effect cost differences between the high and low neurotics became larger as the load increased from two to three and four choice reaction tasks. However the results did not reach the statistical significance level. Regarding the short SOA tasks, the differences in dual task combination costs between the high and low neurotics did not increase as the load was increased by S-R loading manipulation. However, regarding the long SOA tasks, the differences in dual task combination costs between the high and low neurotics became considerably larger as the load was increased by S-R loading manipulation. The results regarding the interaction between degradation effect and neuroticism demonstrate that the cost differences between the high and low neurotics were similar regarding their response times and error rates. Finally, the high neurotics perceived a higher stress level as the load was increased by S-R loading manipulation. Altogether, the results confirm my hypotheses by demonstrating that the high neurotics had lower processing efficiency than the low neurotics to a certain degree as the load increased only on the CES functions whereas the high neurotics perceived higher stress and difficulty as the task became demanding either by S-R mapping manipulation or degradation. Below, I discuss the results in terms of each hypothesis in turn.

My first hypothesis was that the high and low neurotics would not differ on single task processing regarding processing efficiency. The results regarding the response times and error rates in the single tasks showed that the high and low neurotics did not significantly differ. Considering that both the RTs and error rates are not significant, combining these results in processing efficiency indicates that they actually performed similarly on the single task (Flehmig et al., 2010). The results are in line the arousal based theory of neuroticism (1967), PET (1992) and ACT (2007) regarding single task performance in high and low neurotics. According to the theories, high and low neurotics perform similarly on easy tasks (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007) and non-CES demand tasks (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). According to Eysenck (1967), because easy tasks are not stressful the arousal level does not exceed the activation threshold in either high or low neurotics and thus they perform similarly. In line with what PET and ACT suggest, if a task is simple and does not requires much in the way of CES demand, high and low neurotics will perform similarly due to the absence of task irrelevant activities (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). Furthermore, a number of empirical results have confirmed that high and low neurotics do not differ on simple tasks by showing a similar pattern in the results (Robinson & Tamir, 2005; Szymura & Wodniecka, 2003).

The results showed that the interaction between neuroticism level and S-R mapping manipulation regarding the PRP effect costs did not reach a significant level. In the present study, the task demand did not increase in the second task and thus the second task always remained as a two choice reaction task. Therefore, these results in terms of the PRP effects are predictable because the PRP effect is usually derived by subtraction of RT2 in a short SOA from RT2 in a long SOA task. Therefore, it is actually the additional delay in the short SOA compared to the long SOA task. One reason why the interaction effect did not reach a significant level is because the task in the short SOA was very difficult for both high and low neurotics, and task irrelevant activities consumed cognitive resources in both groups. Because the results in terms of the PRP effect and short SOA tasks are very similar, the discussion below, regarding the short SOA tasks, is valid for the PRP effect results as well.

The third hypothesis was that the cost differences between the high and low neurotics would not differ as the load was increased by S-R loading manipulation in the short SOA tasks, as is evident from the similar processing efficiency in both groups. Although I increased the demand in the first task, I found slower RTs in all of the participants not only in the first task but also in the second task. The results showed that the high neurotics were always slower than the low neurotics. However, the cost differences (measured by RTs and error rates) between the high and low neurotics did not become significantly larger as the load increased in both tasks. These results indicate that the cost differences between the high and low neurotics were not influenced by S-R mapping manipulation in the short SOA tasks. The potential reason for that is because I increased the task demand by SOA as well as S-R loading manipulation. It is known that decreasing short SOA is one important way to increase demand on the CES because short SOA give no time for preparation processes. Therefore, the switching and inhibition functions are often impaired in demanding short SOA dual task processing. S-R mapping manipulation in dual tasks also requires more preparation processes (Stelzel et al., 2008a) and it places demand on the switching, inhibition and updating functions (Szmalec et al., 2005). Because the CES has limited capacity, when the demand increases on the CES functions the cognitive resources have to be shared (Dirnberger & Jahanshahi, 2010). Therefore, in dual tasks, as the task demand increases on the CES functions, slower processing can be observed as the expense of task demand (Dirnberger & Jahanshahi, 2010). In this context, increasing the demand from two to three and four choices in the task with short SOA might make it quite difficult for both the high and low neurotics. Higher demand on the CES functions increases worry and arousal level, which causes task irrelevant activities similarly in both groups. Task irrelevant activities interfere with attention during cognitive processing, and thus cognitive resources are consumed in both groups. Consequently, although the high neurotics were always slower than low neurotics, the cost differences between the groups were like two parallel lines that went up as the load increased. In other words, when greater demand was placed by increasing the S-R load, although the participants in both groups took more time to complete the tasks, the dual task cost differences were similar in the short SOA dual task processing. Therefore, increasing the demand by S-R loading failed to be a significant moderator between the high and low neurotics during processing of the short SOA dual tasks. This may be because in addition to S-R loading manipulation, the short SOA was set to 0, which exacerbated the task competition in the bottleneck and caused, relatively, the greatest cost (Jiang, 2004; Pashler, 1994b; Szameitat et al., 2011). Moreover, two choice dual tasks with 0 SOA may have been a threshold for the working memory capacity of the low neurotics and thus the task demand was over the working memory capacity of both the high and low neurotics in the three and four choice dual tasks. When the tasks exceeded the WM capacity of both groups the dual task cost differences remained constant even when the load increased. The cost differences between the high and low neurotics were analogous to two competing cars, one with a 120 km maximum speed and the other with a 220 maximum speed. If they compete from a starting point with their maximum speed the distance between the two cars will increase but after a while (after one hour) the distance between the two cars will always be the same (100 km) regardless of how long they drive for.

The fourth hypothesis was that the cost differences between the high and low neurotics would increase considerably as the load increased in long SOA tasks, as is evident from the slower RTs and higher error rates in the high neurotics. The results showed that the cost differences between the high and low neurotics became larger as the load increased, as is evident from the slower RTs in the high neurotics. Similarly, there was a trend that showed that the high neurotics always made more errors than the low neurotics as the load increased. The potential reason for this is that a higher demand on the CES functions causes greater impairment in task processing in high neurotics compared to low neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Increasing the task demand by S-R loading manipulation requires permanent supervisory control for switching, inhibition and updating (Jahanshahi & Dirnberger 1999). Stelzel et al., (2008) suggest that in dual tasks, four S-R loads for a task require more cognitive control and preparation processes and it is more demanding than dual tasks with two S-R mappings. In line with that, it has been suggested that because response selection is a decisional process, it is associated with the executive functions (Allain et al., 2004; Bunge et al., 2000; Szmalec et al., 2005) particularly switching, inhibition and updating (Szmalec et al., 2005). In this context, the greater task impairment in high neurotics seems to be due to the higher demand on the three CES functions because it has been suggested that high neurotics have higher task impairment only if the task is associated with CES demand (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). It seems that worry and arousal level exceed the activation threshold and increase progressively as the load increases whereas the arousal level remains below the activation threshold in low neurotics during task processing (M. W. Eysenck et al., 2007; Studer-Luethi et al., 2012). Therefore, while cognitive resources are consumed in high neurotics because of higher task irrelevant activities, low neurotics still have relatively available cognitive resources during the task processing because their arousal level does not pass the activation threshold (M. W. Eysenck et al., 2007; Studer-Luethi et al., 2012).

My fourth hypothesis is confirmed in the analysis of tasks 1 and 2 regarding both the response times and error rates in high and low neurotics. Although I increased the load in task 1 only, I found the interaction effects regarding the response loading and neuroticism in both task 1 and task 2. According to Pashler (1994) greater demand in task 1 prolongs RT1 as well as RT2 to the same degree because the second task has to wait until the first task is processed in the bottleneck. Pashler (1994, 1993) explains this with an analogy of a bank teller (bottleneck) and two customers (first and second tasks). If there are two customers in the queue and one bank teller on the duty, the bank teller has to deal with the customers one by one. If the first customer dawdles with bank teller for 5 minutes, both customers will be delayed for five minutes because the second customer has to wait until the first customer leaves. I observed that a higher load in the first task caused a delay in the second task in all of the participants. In addition, because the arousal level easily increases and it causes greater task irrelevant activities in high neurotics in demanding tasks, these higher task irrelevant activities probably place additional demand on the tasks, and thus the cost differences between high and low neurotics increase as the load increases in long SOA tasks. In detail, while the high neurotics were 69ms RT1 and 79ms RT2 slower than the low neurotics during the processing of the two choice dual tasks, they were considerably slowed down compared with the low neurotics during the processing of the three choice dual tasks (118ms RT1 and 86ms RT2) and four choice dual tasks (171ms RT1 and 123ms RT2). Increasing the demand by insertion of additional S-R mappings led to greater dual task cost differences between the high and low neurotics from the two to four and three to four choice dual tasks.

One important result is that a greater load on the updating function may cause considerable task impairment in high neurotics. In the previous tasks (chapter 3), the task demand increased on the three functions. However a higher proportion of the demand was on switching and inhibition because in each switching trial the participants were required to re-schedule the task order (Luria & Meiran, 2003; Szameitat et al., 2002). There were always two S-R mappings that had to be updated. In the present experiment, there was also higher demand on the three functions as the load increased but the proportion of the demand on the functions may have changed. The participants still needed to inhibit the second task processing until the first task had been processed in the bottleneck and then inhibit the first task for the second task processing (De Jong, 1995b; Luria & Meiran, 2003). They have to switch focus of bottleneck from first task to the second task (De Jong, 1995b; Luria & Meiran, 2003). Thus, when the load increased, more tasks related information had to be involved in the switching and inhibition functions. From this point of view, demand on the switching and inhibition functions increased. Moreover, because the S-R load increased in a progressive manner, the participants were required to maintain more stimuli and response choices in the CES as the load increased (Stelzel et al., 2008a). Therefore, a higher proportion of demand was placed on the updating function compared to the previous experiments (chapters 3 and 4). The results showed that increasing the demand on the updating function as well may maximize the demand on the three CES functions, which becomes very difficult for both high and low neurotics in short SOA tasks. However, in long SOA tasks, the task might be very difficult in high neurotics but not so much in low neurotics therefore, the dual task costs was greater for high neurotics compared to low neurotics as the load increase.

So far, I have shown that the cost differences between high and low neurotics did not become larger when the demand was increased by the SOA (0 SOA) and S-R loading manipulation, either in terms of the RTs or the error rates. However, the cost differences between the high and low neurotics considerably increased when the demand was increased by S-R loading manipulation with a long SOA (1000 SOA). Probably, the task became very difficult in the short SOA tasks and the arousal level exceeded the activation threshold in both groups. Therefore, higher task irrelevant activities interfered with the attention and cognitive resources consumed in both the high and low neurotics. In the graphs, it can be seen that the two lines go up in parallel as the load increases. However, in the long SOA tasks, the arousal level exceeds the activation threshold in high neurotics only and higher task irrelevant activities cause task impairment because of a scarcity of cognitive resources whereas the low neurotics still have cognitive resources to process the task faster than the low neurotics. In the graphs, the gap between the two lines that go up becomes larger as the S-R load increase.

To understand whether the increasing cost differences between the groups were specific to increasing the demand on the central executive system, I also designed a dual task with a degraded stimulus in which the task was made more demanding in the perceptual stage but not in terms of working memory (Barch et al., 1997). The formulated hypothesis was that high and low neurotics would not differ in terms of the task difficulty at the perceptual stage. In other words, if the impairment was due to the load on the CES then no dual task cost differences would be found between high and low neurotics regarding processing of the degraded and non-degraded three choice dual tasks. The results demonstrated that both the high and low neurotics completed the tasks with longer response times in the degraded version compared with the non-degraded version, which indicated that the degraded version of the dual task was more difficult and fitted the research purpose (Barch et al., 1997; Rubinstein et al., 2001). Furthermore, I observed that the dual task cost differences between the high and low neurotics remained constant as the task difficulty increase by stimuli degradation (i.e. from the non-degraded to degraded dual task processing). These results are in line with the assumption of ACT, which suggests that impairment during the processing of a dual task is caused by the demand placed on the central executive system whereas demand on other processes does not influence task processing in high neurotics (Eysenck et al, 2007). Because two tasks can be processed together in the perceptual and motor execution stages, higher demand caused by stimuli degradation does not influence the CES in the bottleneck (Marois & Ivanoff, 2005; Meyer & Kieras, 1997a; Pashler, 1993; Pashler, 1994b).

With respect to the relationship between perceived stress and neuroticism level in dual task processing, the results confirmed the formulated hypothesis. Accordingly, I found that both the high and low neurotics perceived the single task as easy and non-stressful. Therefore, no differences were found in terms of the perceived stress level in the single task processing between the groups. On the other hand, the high neurotics felt more stressful and difficult in the dual task processing compared to the low neurotics as the load increased. The results are in line with Eysenck (1967), Eysenck & Calvo (1992) and Eysenck et al., (2007) who suggest that high neurotics perceive a higher stress level in demanding task processing. In particular, these results provide evidence that perceptually high neurotics feel higher stress and difficulty than low neurotics.

Also, high neurotics perceive higher stress and difficulty in degraded stimuli, which may lead to a new argument. Eysenck (1967) suggests that high neurotics perceive higher stress and difficulty in demanding tasks, which is as indication of a higher arousal level. If a higher arousal level causes task impairment, then why did the high and low neurotics not differ considerably as the load increased due to the degradation effect? Some empirical studies have found that when stimuli are negative they may cause higher arousal, and that high neurotics had a higher impairment compared to when the task included neutral stimuli (Bishop et al., 2004; Dolcos & McCarthy, 2006; Mogg et al., 1993). One possible reason for this is that in those studies threatening emotional stimuli were used that are directly associated with worry and inner words in high neurotics. M. W. Eysenck et al., (2007) suggested that inner words contribute to task irrelevant activities and may influence task processing. However, in the current study, degradation was not directly associated with worry and inner words because there were no emotional cues that may have contributed to negative affectivity in high neurotics. Another possible reason is that subjective measures are different from objective measures (M. W. Eysenck & Calvo, 1992). For example, one may perceive a task as very stressful and difficult. However in an objective measure both high and low neurotics may be the same physiologically i.e. regarding their electro dermal responses (M. W. Eysenck & Calvo, 1992). I took the prediction of Eysenck (1967) regarding subjective measures, and the current evidence showed that indeed the degraded task was stressful and difficult; however, higher perceived stress and difficulty as an indication of a higher arousal level in high neurotics did not increase the cost differences between high and low neurotics when the demand was increased by stimuli degradation.

In conclusion, the results demonstrate that because short SOA tasks are very difficult the cost differences between high and low neurotics do not become larger as S-R mapping increases due to a scarcity of cognitive resources in both high and low neurotics. However, in short SOA tasks, the cost differences between high and low neurotics dramatically increase because the arousal level exceeds the activation threshold in high neurotics but not in low neurotics. Furthermore, the results show that the cost differences did not become larger as the task difficulty was increased by stimuli degradation (degraded vs non-degraded tasks). Finally, I found that high neurotics perceived higher stress and difficulty as the task demand was increased either by S-R mapping manipulation or stimuli degradation. Taken together, the results are sufficient to show that greater task impairment in high neurotics is associated with CES demand but is not associated with other demands such as at the perceptual stage or VSSP. Therefore, this study confirms that the detrimental effect of neuroticism impairs the CES functions whereas it has no major effect on the other systems. In the final study, I explore neural correlations of greater impairment in high neurotics compared with low neurotics in dual task processing.

6 Chapter – Neuroticism related differences in the functional neuroanatomical correlates of dual task processing. An fMRI study

6.1 Introduction

Eysenck (1967) proposed that high neurotics perform worse than low neurotics on difficult tasks rather than easy tasks. Because high neurotics are inclined towards negative affectivity, they are literally ‘worriers’, so their arousal level, which can cause task impairment, easily increases in difficult tasks (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967).

ACT (M. W. Eysenck et al., 2007) more specifically suggests that high level neuroticism mainly impairs the CES functions in demanding cognitive task processing. A key feature of greater task impairment in high neurotics is a higher worry and arousal level, which causes greater task irrelevant activities in cognitively demanding tasks (M. W. Eysenck, 1985; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). This means that high neurotics experience on average higher worry and arousal and consequently higher task irrelevant activities than low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; M. W. Eysenck & Derakshan, 2011). During demanding task processing the CES functions require higher sustained attention and therefore the major focus of attention is allocated to the CES functions. Because high neurotics have to deal with task irrelevant activities as well as task related activities the focus of their attention has to be shared between them and thus higher task impairments occurs because of investing less efficient mental effort (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011; Szymura & Wodniecka, 2003).

One distinctive way to test the effect of neuroticism in relation to the CES functions is the dual-task paradigm of the psychological refractory period (PRP) because it allows for high experimental control (Logan & Gordon, 2001; Pashler, 1994a). The task demand can be easily manipulated in regard to the CES functions (Luria & Meiran, 2005; Szameitat et al., 2016). It has been found that PRP dual task performance requires extensive use of the switching, inhibition and updating functions of the CES (De Jong, 1993; De Jong, 1995a; Luria & Meiran, 2003; Szameitat et al., 2016). For example, in PRP dual tasks, when both tasks are performed simultaneously, the tasks can only be processed one at a time in the response selection, which maps the presented stimuli onto the required button presses, i.e. they constitute a processing bottleneck (Pashler, 1994a). This bottleneck results in demands for additional executive control functions to coordinate the processing of the tasks, e.g. by sequencing the task order, by inhibiting the second task, which has to wait while the bottleneck processes the first task, and by switching the bottleneck mechanism towards the second task once the processing of the first task processing has finished (De Jong, 1993; De Jong, 1995a; Luria & Meiran, 2003; Szameitat et al., 2016). Also, the task related rules and contexts have to be updated during the task processing (Stelzel et al., 2008b). These demands all arise due to the presence of a processing bottleneck, so they are dual-task specific and not present during the performance of single tasks (Pashler, 1994a). Based on this argument, my previous behavioural studies (chapter 3-5) showed that high neurotics had higher dual task combination costs and PRP effects compared to low neurotics when the demand on the three CES functions increased. For example, high and low neurotics did not differ in terms of single task processing because single tasks require almost no the CES functions. Similarly, the high and low neurotics did not significantly differ when the task demand increased in other ways i.e. demand on the storage systems such as in the VSSP by SWM task (chapter 2) or demand on the perceptual stage by stimuli degradation in the dual task (chapter 5). However, the high neurotics had greater task impairment in the dual task processing as the SOA decreased because this placed considerable demand on the CES functions. Therefore, I conclude that high neurotics perform worse than low neurotics on dual tasks, which require extensive use of the CES functions (H. J. Eysenck, 1967; M. W. Eysenck et al., 2007) compared to single tasks, which require almost no CES functions because the detrimental effect of high neuroticism mainly impairs the CES functions during dual task processing (M. W. Eysenck et al., 2007).

While these mechanisms are well understood in terms of my behavioural findings, which are also supported by cognitive models and previous empirical studies, knowledge about their functional neuroanatomical correlates is sparse. More generally, neuroimaging studies have demonstrated that high neurotics have decreased activation of the fronto-parietal executive control network, which links the dorsolateral prefrontal cortex (DLPFC) to the anterior cingulate cortex (ACC) and parietal lobe, e.g. during a working memory N-back task (Dima et al., 2015). In addition, high neurotics were found to have decreased grey matter volume in the prefrontal areas compared with low neurotics (Bjørnebekk et al., 2013; DeYoung et al., 2010). Some studies have also shown that the functional connectivity between the prefrontal cortices and other brain regions is weaker in high neurotics than in low neurotics (Bjørnebekk et al., 2013). These lateral-prefrontal areas have frequently been associated with the executive functions, and so it seems likely that high levels of neuroticism will be associated with a deficit in the executive functions (Rottschy et al., 2012).

The dual mechanism of control (DMC) theory explains that the reason for decreased activation in the cognitive control regions is due to high task irrelevant activities, which cause the activation of reactive control mechanism (see section 1.4.5). In detail, as a reminder, DMC proposes two control mechanisms, proactive and reactive control mechanisms, during cognitive task processing (Braver et al., 2007; Braver, 2012; Burgess & Braver, 2008) (see section 1.4.5). The proactive control mechanism keeps the focus of attention on task related information and thus it helps to process the task efficiently (Braver et al., 2007; Broyd et al., 2009). It is associated with increased activation in the cognitive control regions such as the LPFC (DLPFC, VLPFC) and ACC. The reactive control mechanism keeps the focus of attention on task irrelevant activities, which is a consequence of a threatening situation. Therefore, it activates when task irrelevant activities are increased and negatively influences cognitive task processing (Braver, 2012) because task irrelevant activities are associated with a default mode network (i.e. the medial frontal cortices such as the anterior regions (BA 10) and temporal parietal regions such as the posterior cingulate cortices (BA 31), and the left inferior temporal lobe (BA 37) (Broyd et al., 2009; Burgess & Braver, 2008; Gray et al., 2002; Uddin, Clare Kelly, Biswal, Xavier Castellanos, & Milham, 2009). In this context, when a cognitively demanding task has to be processed efficiently, which requires proactive control, the cognitive control regions are activated and the default network regions tend to be less active (Braver, 2012; Burgess & Braver, 2008; Drevets & Raichle, 1998). However, because worry and a higher arousal level increase task irrelevant activities in high neurotics, they are inclined to use a reactive control mechanism, which leads to decreased activation in the cognitive control regions during demanding task processing (Braver, 2012; Gray et al., 2002). Therefore, under a demanding condition, an increased worry related arousal level leads to higher task irrelevant activities, which activate reactive control in high neurotics. Thus, in high neurotics, high task irrelevant activities disrupt task processing due to having to perform tasks concurrently that are demanding (Braver et al., 2007; Braver, 2012; Gray et al., 2002). At first, they fail to employ cognitive resources efficiently for task related activities (Burgess & Braver, 2008; Power & Dalgleish, 1997). Taken together, high neurotics may be inclined towards reactive control and, therefore, in demanding tasks they perform worse during task processing (Braver, 2012; Gray et al., 2002) because they cannot implement cognitive resources for task relevant activities (Bishop et al., 2004; Bishop, 2009; Braver, 2012). Low neurotics may be inclined towards proactive control and therefore they select task relevant activities earlier because they have a lower arousal level and less worry (Braver, 2012; Gray et al., 2002). Consequently, high neurotics may have higher costs with lower activation in the cognitive control regions compared to low neurotics during demanding cognitive tasks (Bishop et al., 2004; Bishop, 2009; Braver, 2012).

Decreased activation, which is accompanied by higher dual task cost, has been found in a few PRP studies. For example, in some PRP studies, two groups were compared: one with higher cognitive functioning and the other with lower cognitive functioning (such as younger vs older) (Erickson et al., 2007; Hartley, Jonides, & Sylvester, 2011). Higher dual task cost and at the same time decreased activations have been reported within a group with low cognitive functioning (Erickson et al., 2007; Hartley et al., 2011). It has been suggested that decreased activation in low cognitive functioning groups might be due to inefficient recruitment of cognitive resources (Hartley et al., 2011). Although the research interest of such studies is not related to the current study, they support the current hypothesis by showing that higher dual task costs can often be associated with decreased activations.

More recently, Szameitat et al., (2016), found this pattern of results i.e. decreased dual task specific activation accompanied by higher dual task cost in normal healthy controls. One potential reason for such a correlation is less preparation during task performance (Szameitat et al., 2016). In other words, some participants might not put efficient mental effort into the task during the performance of concurrent tasks because they may be less prepared during the task performance (Szameitat et al., 2016). Preparation was previously defined as mental processes for switching tasks just before task execution (Szameitat et al., 2016). As explained in section (1.3.3) the preparation process has a considerable effect on interference (De Jong, 1995a; Szameitat et al., 2016). During dual task performance, participants require more and better preparation to reduce the dual task cost. However, if they do not prepare well, a high dual task cost may be accompanied by lower neural activation in dual task specific areas (De Jong, 1995a; Szameitat et al., 2016). In other words, less preparation may cause a higher dual cost (De Jong, 1995a) and be followed by lower neural activations in dual task related areas (Szameitat et al., 2016). For example, in dual task processing as compared to single tasks, higher preparation is required to implement the switching, inhibition and updating functions in an appropriate time and context (De Jong, 1995a; Luria & Meiran, 2003). However, when the SOA is short there is not time for preparation (De

Jong, 1995a; Luria & Meiran, 2003). Therefore, additional demand is placed on the CES functions beyond the demand incurred by the bottleneck (De Jong, 1995a; Luria & Meiran, 2003). Although neuroticism was not controlled in the study of Szameitat et al., (2016), the results support my current statement by showing higher dual task cost with decreased activation in dual task specific areas. Translating this into the current study, a worry related increased arousal level may prevent high neurotics from carrying out better preparation compared to low neurotics during dual task performance. As a result, high neurotics may put less mental effort into the task due to less preparation, which exacerbates the interference in dual tasks.

The present study aimed to evaluate the influence of neuroticism on the functional neuroanatomical correlates of the PRP dual task. I compared the brain activation patterns of high and low neurotics during single- and dual-task performance. More specifically, I employed the dual-task paradigm of the psychological refractory period because of its strong association with the three CES functions (De Jong, 1995a; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016) and the high level of experimental control that it allows (Logan & Gordon, 2001; Meyer & Kieras, 1997a; Pashler, 1994b). In the current study, this paradigm consisted of two forced-choice response tasks (one auditory-manual and one visual-manual), which were performed either separately as single-tasks or concurrently as dual-tasks. Thus, the task demand increased from the single task to the dual task. Consequently, I tested high and low neurotics on a single task, and a dual task with a short SOA. Based on the arguments made in the above paragraphs, I proposed a general pattern of behavioural results in the previous experiment (chapter 3-4) regarding dual task combination costs in high and low neurotics. In detail, I proposed that due to the difficulty and nature of the additional processes, the high neurotics would show performance impairments in the dual-task conditions, but these would be less evident for the single-task performance. This can be assessed by so-called behavioural dual-task costs, i.e. by the performance difference between both types of tasks, dual-tasks and single-tasks.

Regarding the functional neuroanatomical correlates, it is important to determine brain activation that is specific to dual-task processing because this activation cannot simply be explained by single task processing and thus it is only related to dual task processing. Generally, in the literature review chapter, I mentioned that in PRP dual task studies such dual-task specific activations are in the lateral and medial prefrontal cortices (Sigman &

Dehaene, 2005; Stelzel et al., 2008b; Szameitat et al., 2002). In detail, it has been shown that dual task specific areas are often associated with greater neural activation in the lateral prefrontal cortices (LPFC) (for task coordination: middle frontal gyrus (MFG), inferior frontal gyrus (IFG), inferior frontal sulcus (IFS)) (Dux et al., 2006; Erickson et al., 2005; Schubert & Szameitat, 2003; Stelzel et al., 2008a; Szameitat et al., 2002), and medial prefrontal cortex (medPFC) (maintenance and error execution, anterior cingulate cortex; (ACC)) (Carter et al., 2000; MacDonald et al., 2000; Szameitat et al., 2006) during dual task processing. Based on previous evidence of functional neuroanatomical correlates of the executive functions in highly neurotics, I expected that the high neurotics would show decreased dual-task specific activation in the lateral and medial prefrontal cortices compared to the low neurotics.

To assess the dual task specific areas, I have used a cognitive subtraction method to compose the contrasts. In the behavioural studies, I have calculated the dual task combination costs by subtracting the average of the single tasks from the average of the dual tasks i.e. DT0-ST. Therefore, with respect to the functional neuroanatomical correlates, I have composed a contrast to assess the dual task specific areas, which cannot simply be explained by the performance of the single tasks (Szameitat et al., 2011). The contrasts are $[DT\,0 - ST_{Auditory} - ST_{Visual}]_{Low\ Neurotics} - [DT0 - ST_{Auditory} - ST_{Visual}]_{High\ Neurotics}$.

Taken together, I aim to investigate the effects of neuroticism on the functional neuroanatomical correlates of a single task, and dual tasks with short SOA. To do so I have formulated a hypothesis as follows:

I. High neurotics will show higher dual task combination costs and at the same time decreased dual-task specific activations compared to low neurotics.

6.2 Methods

6.2.1 Participants

To create extreme groups of high- and low-neurotics (High-N and Low-N, respectively), I screened participants using the 24-item neuroticism scale of the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975). One participant was excluded because of claustrophobia. From the N (24-item neuroticism scale of EPQ) screened people, 32 participants took part in the final MRI experiment: 15 (7 women) in the High-N group (mean

EPQ score=18, range=16–24) and 17 (8 women) in the Low-N group (mean EPQ score= 3.89, range=0–6). The two groups were roughly matched for age (High-N = 21.36 and Low-N=23.50) and gender. All of the participants were right-handed, as assessed by the Edinburgh Inventory (Oldfield, 1971) and had normal or corrected to normal vision. None of them were known to have any neurological or psychiatric disorders. Before participation each participant gave their written informed consent. The participants were paid £20 for 40 minutes participation. The study was approved by the Department of Life Sciences ethics committee at Brunel University.

I employed the same exclusion criteria as indicated in the previous chapters (see chapter 2) such as scoring over 15 in the Beck depression inventory (BDI), and the presence of any past or current major medical, neurological or psychiatric illness etc.

6.2.2 Tasks

Generally, the tasks were very similar to the behavioural dual task experiment in chapter 3 except for the random-order task, which was not included in this experiment. The block and trial numbers; registered time durations; and experimental conditions were also changed and adapted for efficient data acquisition in the scanner. Therefore, I will explain the methods to clarify all points. The participants had to perform an auditory and a visual two-choice reaction task. These tasks were performed block-wise either alone (single-task conditions) or together (dual-task conditions). While lying in the fMRI scanner, the participants viewed a projection screen via a mirror. They responded on two separate fMRI-suitable keypads, each with four keys.

6.2.2.1 Single Tasks

There were two single task conditions, visual and auditory conditions.

The visual single task to be performed by the participants was gender discrimination (female vs. male). The visual single task consisted of male and female faces. Each face stimulus was randomly drawn from a set of 120 different faces (60 males, 60 females; black-and-white images with an oval mask covering most of the hair except for the fringe). A male face required a fast button-press response with the right index finger and a female face required a button press with the right middle finger.

The tasks were presented in blocks of 8 trials, lasting 26.6s. Before each block the task of the upcoming block was presented for 5.9s. Each condition was presented 8 times in an individually randomized order. A trial in the VIS condition started with a blank grey screen for 150 ms followed by a fixation period of 250 ms. After the fixation period, a picture of either a male or a female face was presented for 345 ms. From the start of the stimulus presentation, the participants had 3075ms to respond. Afterwards, either error feedback ('Error') or a fixation cross was presented for 250ms.

The auditory single task (syllable task) was identical to the visual task in terms of the blocks, trials and time durations. The auditory single task to be performed by the participants was syllable discrimination (ha-ha vs. ya-ya). Each syllable was randomly drawn from a set of 30 different syllables (15 /haha/, 15 /yaya/) recorded from several different speakers. Key mapping for the syllable 'ha ha' was to be done with their left index finger and for 'ya ya' with their left middle finger by pressing the second button next to the first key on the keypad. the other characteristics of the auditory task were identical to the visual condition.

6.2.2.2 Dual Tasks

In the dual-task conditions, the two single tasks (visual and auditory) indicated above had to be performed together. For this purpose, both stimuli (auditory and visual) were presented simultaneously with 0 ms SOA. A special instruction that indicated the task order was presented just before the stimulus presentation. The order of the task presentation was constant within a block and was balanced across blocks, so that an equal number of trials started with a task order either (visual=> auditory) or (auditory=>visual). Dual tasks with short SOA had two separate conditions (visual=> auditory) and (auditory=>visual). Thus, in total there were two fixed dual-task conditions.

Similar to the single tasks, each dual task condition was presented 8 times in an individually randomized order. In dual tasks with a short SOA, the trial started with a blank grey screen for 150 ms followed by a fixation period of 250 ms. After the fixation period the visual and auditory stimuli were presented simultaneously for 345 ms. The trial lasted for 3325 ms in total and the selection of stimuli was fully random. The key mapping was always identical to the visual and auditory single tasks.

6.2.2.3 Base

In addition to the dual task conditions, a resting baseline condition (BASE) was also included. The participants were required to keep still and look at a white fixation cross that was presented in the middle of the screen. The base condition was randomized among all of the other conditions.

6.2.3 Design of measurement

In this study, I applied a block design approach. The tasks consisted of 56 blocks. Overall, there were 5 conditions which are relevant to current report: auditory single task; visual single task, DT (0 SOA) Auditory=> Visual; DT (0 SOA) Visual => Auditory; and BASE. Each condition consisted of 8 blocks and each block (except for the BASE) consisted of 8 trials. One block lasted 32.5 seconds. 5 seconds of these 32.5s was an interval that separated the blocks and served as an instruction period. The rest of the time (27.5 second) was used for the tasks. All of the conditions were randomly distributed and counterbalanced throughout the experiment.

6.2.4 Scanning Procedure

The image acquisition took place in a 3 tesla fMRI scanner (Trio, Siemens, Erlangen, Germany) equipped with a 12-channel array head coil at Royal Holloway University, Egham, Surrey, UK. The participants lay on the scanner bed and wore a headphone that was used to both reduce the noise and present the audio tasks. Furthermore, two cushions were placed, one on each side of the head, to minimize head movement. The sounds were tested through the headphones to confirm that they worked properly just before the scanning began. The participants were encouraged to keep still while they were in the scanner.

A Sanyo LCD projector (PLC XP1000L, native resolution = 1024 x 768) was used to project the visual stimuli onto the screen. The participants viewed the visual stimuli through an angulated mirror equipped with an above of the head coil in the bore of the magnet. 35 axial slices (192×192 mm FOV, 64×64 matrix, 3x3 mm in-plane resolution, 3 mm thickness, no gap, interleaved slice acquisition) were acquired using a BOLD-sensitive gradient echo EPI sequence (TR 2.5 s, TE 31 ms, 85° flip angle). The experiment consisted of two functional runs and one anatomical scan. In between the functional runs, the participants were informed that no tasks were to be performed for 5 mins and they were asked to keep still during this time in order to acquire anatomical T1 weighted images. High-resolution whole-brain images were acquired from each participant using a T1-weighted MPRAGE sequence (TR 1900 ms, TE 3.03 ms, 11° flip angle, 176 slices, 256×256 mm FOV, 1×1×1 mm voxel size). Two functional runs with 364 volumes each were acquired, with each volume sampling all 35 slices. Each functional session lasted for approximately 15 mins (7 conditions x 4 repetitions each x 32.5 seconds each = 910 s / 60s = 15.166 min). At the end of the study all of the participants were given a debriefing form (appendix J).

6.2.5 Data Analysis

The MRI data were analysed using SPM 12. First, the origin of the structural as well as functional images was manually aligned with the anterior commissure. Next, the head motion was corrected (Realign & Unwarp). The anatomical and functional images were normalized to MNI space using unified segmentation. Finally, the functional data were spatially smoothed using a Gaussian kernel with an FWHM of 8mm. The normalization and registration success was validated by visual inspection.

The statistical analysis was based on a voxel-wise least-squares estimation using the general linear model for serially auto-correlated observations (Friston et al., 1994). Because the current study used a blocked fMRI design, a boxcar function, convolved with a canonical HRF without derivatives, was used to model the BOLD response. A temporal high-pass filter with a cut-off frequency of 1/170 Hz was applied. Individual contrast maps were calculated for all contrasts of interest (see "Results" section), and the second-level analysis was based on independent-sample *t*-tests. All of the resulting *t*-maps were thresholded at $p < .005$ (uncorrected) and only clusters significant with $p < .05$ (FWE corrected) were considered. A recent study has shown that cluster level inference using these parameters, i.e. rather strict thresholding for generating the cluster map, is generally accurate (Eklund, Nichols, & Knutsson, 2016). The anatomical locations and Brodmann's areas were determined using the Automated Anatomical Labeling toolbox (Eickhoff et al., 2005; Tzourio-Mazoyer et al., 2002). The contrast was Dual Task SOA 0 – Auditory Single-Task – Visual Single Task, i.e. [1-1-1] for high and low neurotics for all of the comparisons of interest.

Also, the correlations were calculated to examine any relationships between the bold signal in the dual task specific areas and the participants' EPQ scores or dual task costs, either in the whole group (high and low neurotics together) or separately for each group. To do that, I used the beta-values of each individual participant taken at the group-peak voxel derived from the first-level stats. Thus, the correlations between these beta-values and the neuroticism scores or behavioral dual task costs were calculated.

6.3 Result

6.3.1 Behavioural Results

To test whether the level of neuroticism affected behavioural performance in the dual-task situation, I calculated two 2x2-factorial ANOVAs (one for response times (RTs) and one for error rates) with the within-subject factor task (single tasks vs. dual task) and the between subject factor neuroticism (Low-N vs. High-N). For the RT analysis, I averaged the RTs of the two single tasks, and I also averaged the RTs of the first task (RT2s) of the two dual-task orders. The results showed that the RTs in the dual-task were significantly slower than in the single-tasks (main effect task; $F(1, 30) = 325.8$. $p < .001$), and that the RTs were significantly slower for the High-N group than for the Low-N group (main effect neuroticism; $F(1, 30) = 15.6$, $p < .001$). Importantly, the interaction between the task and neuroticism was also significant, indicating that the dual-task costs were higher for the High-N group than the Low-N group ($F(1, 30) = 5.9$, $p < .05$). The error rates showed the same pattern, but some of the effects did not reach statistical significance (main effect task: $F(1, 30) = 65.6$, $p < .001$; main effect neuroticism: $F(1, 30) = 1.9$, $p = .18$; interaction: $F(1,30) = 3.1$, $p = .087$).

Generally, the results show that the high neurotics had a higher dual task cost than the low neurotics. In addition, it might be considered whether there is a correlation between the dual task cost and the N scores i.e. as one increase so does the other. Therefore, I also examined the correlations between the dual task cost and the EPQ score, which were calculated in two ways. First, when calculating the correlations across the whole sample (i.e. high and low neurotics so that the EPQ scores span the whole range of the scale), the EPQ score is positively correlated with dual-task performance as such (i.e. response times (RT1) of two dual tasks (RT1) in the dual-task condition, $r = .586$, $p < .001$) as well as dual-task costs (i.e. dual-task RTs minus single-task RTs, $r = .880$, $p < .001$). Second, when calculating the separate correlations for the high and low neurotics (i.e. EPQ scores are much more restricted to a narrow range of only either high or low scores, respectively), these correlations are not significant when they are calculated individually for each group (all $p > .590$).

6.3.2 FMRI Data

I used the cognitive subtraction method to assess dual-task specific activation, and thus I calculated one contrast, the Dual Task SOA 0 – Auditory Single-Task – Visual Single Task, i.e. [1 -1 -1] (Szameitat et al., 2011), individually for each participant during the first level statistics. During the second level statistics, I tested for group differences by comparing the contrast images of the above contrast of the High-N participants with those of the Low-N participants using an independent sample t-test. Thus, these contrasts test whether the high and low neurotic participants differed in their dual-task specific activation. The results regarding the contrast indicate dual task specific activations compared to single tasks. If the contrast reveals activation, it is dual-task specific activation, i.e. it cannot be explained by the summed activation of the single-tasks (Szameitat et al., 2011).

6.3.3 Neuroimaging Results

The results regarding the contrast $[DT\ 0 - ST_{Auditory} - ST_{Visual}]_{Low\ Neurotics} - [DT0 - ST_{Auditory} - ST_{Visual}]_{High\ Neurotics}$ i.e. [1-1-1] showed higher activations in the lateral and medial prefrontal cortices in low neurotics compared to high neurotics (Figure 6.1). In more detail, the cluster in the lateral prefrontal cortex is extended mainly along the mid-to-anterior middle frontal gyrus (BA 46), extending into the inferior frontal sulcus/gyrus (BA 47) and superior frontal sulcus/gyrus (BA 10). The cluster in the medial prefrontal cortex extended from the medial superior frontal gyrus (BA 8/9) inferiorly into the anterior cingulate cortex (ACC, BA 32) (see table 6.1). The reversed contrast (i.e. higher dual-task specific activation in High-N as compared to Low-N) did not reveal any significant voxels in the frontal brain regions, even at a lowered voxel level threshold of $p < .05$ (uncorrected).

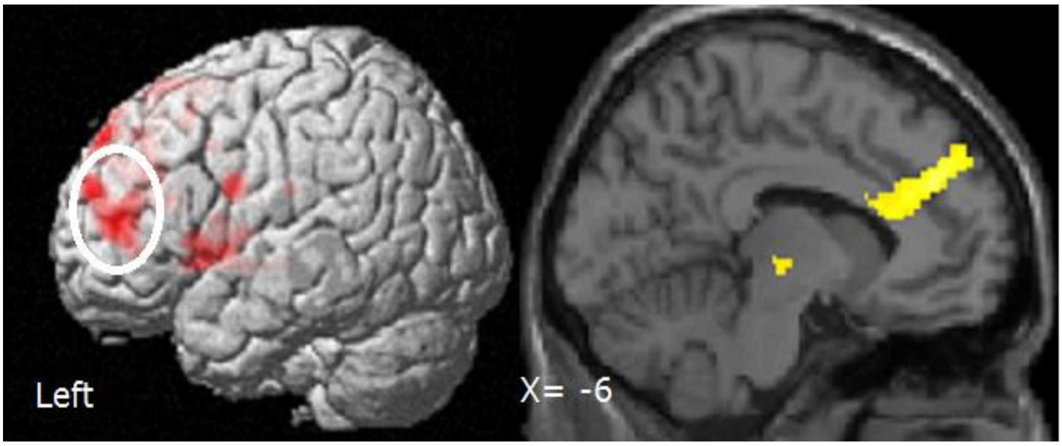

Figure 6-1 Imaging data. higher dual-task specific activation in the left lateral prefrontal cortex (left panel, circled area) and medial prefrontal cortex (right panel) for low compared to high neurotics as assessed by the contrast [DT – ST

Auditory – ST Visual] low Neurotics – [DT – ST Auditory – ST Visual]high Neurotics. Maps thresholded at p < .005 (uncorrected), clusters significant at p < .05 (FWE corrected).

Anatomical area	*BA*	*x, y, z*	*t / p(uncorr)*	*Cluster-level p(FWE)*	*Cluster volume (mm^3)*
Cluster 1				.049	5656
middle frontal gyrus	46	-32, 46, 12	4.52 / .00004		
superior frontal gyrus	10	-28, 56, 24	4.17 / .00012		
inferior frontal gyrus	46	-44, 44, 6	3.85 / .00029		
Cluster 2				.004	10096
medial superior frontal gyrus	8/9	2, 52, 44	4.45 / .00005		
anterior cingulate cortex	32	4, 38, 20	4.25 / .00012		
medial superior frontal gyrus	9	-10, 42, 28	3.88 / .00027		

Table 6-1 Areas exhibiting significantly higher dual-task specific activation in low neurotics compared to high neurotics (contrast [DT0 – ST Auditory – ST Visual] low Neurotics – [DT0 – ST Auditory – ST Visual] high Neurotics). Notes. BA Brodmann's area. x, y, z MNI coordinates of local peaks. t/p(uncorr) voxel-level t-value and uncorrected p-value of local peaks.

6.3.3.1 Correlations between neuroticism level and dual task specific brain activations

If the correlations are calculated across the whole sample, then the main driver of any correlation between the EPQ scores and the beta values in the six lateral and medial frontal areas is the profound group difference in the neuroticism scores of the Eysenck Personality Questionnaire (EPQ). Indeed, the EPQ correlates negatively with all six of the reported lateral and medial prefrontal areas (all r between -.438 ($p < .05$) and -.574 ($p < .001$), indicating that high neurotics show lower beta values. However, these correlations seem to be driven by the group difference between the high and low neurotics, because when the high and low neurotic groups are analysed separately, not one correlation (with r-values distributed around 0) was significant (p-values typically > .4).

Moreover, if correlations are calculated across the whole sample, then the dual-task costs correlate negatively with all six prefrontal areas (r-values -.382 – -.547, all $p < .05$), indicating higher dual task cost accompanied with lower beta values. Again, these correlations are not significant when calculated individually for each group. This pattern is observed for all of the lateral and medial prefrontal local peaks.

6.4 Discussion

The behavioural results demonstrated that while all of the participants, low and high neurotics, were slower in the dual-task condition compared to the single-task condition, this slowing down was significantly more pronounced in the high neurotics compared with the low neurotics. These higher behavioural dual task combination costs were accompanied by higher dual-task specific activation in the prefrontal cortices in the low neurotics compared to the high neurotics. In more detail, regarding the dual task combination costs, the neuroticism related group differences showed higher activations in the low neurotics compared to the high neurotics in the left lateral prefrontal cortex mainly along the middle frontal gyrus, extending into the inferior and superior frontal gyri, as well as the medial prefrontal areas reaching from the anterior cingulate gyrus into the medial superior frontal gyrus. Finally, when calculating the correlations there was a strong positive correlation between the EPQ scores of the participants and their dual task costs and these variables (EPQ scores, and dual task cost) were negatively correlated with the bold signals in the dual task specific regions. However, when the correlations were performed separately for each group, none of these (EPQ, dual task cost and bold signals) variables were correlated at the significance level. Taken together, the results confirm my hypotheses by showing lower activations in the dual task specific areas in high neurotics compared with low neurotics.

The anatomical areas in the first contrast, the lateral and medial prefrontal cortices, have repeatedly been reported to be involved in the performance of PRP dual-tasks (Sigman & Dehaene, 2005; Stelzel et al., 2008b; Szameitat et al., 2002; Szameitat et al., 2016). It has been suggested that these areas are involved in the executive functions, which resolve interference and coordinate the processing of the tasks at the stage of the processing bottleneck (Szameitat et al., 2002; Szameitat et al., 2016). For example, it has been suggested that inhibition of the first task until the second task is processed is often associated with IFG activations (Konishi et al., 1999; Levy & Wagner, 2011; Schubert & Szameitat, 2003; Szameitat et al., 2006; Szameitat et al., 2002; Szameitat et al., 2016), and therefore it is assumed to be associated with the inhibition function of the central executive system (Konishi et al., 1999; Levy & Wagner, 2011; Szameitat et al., 2016). Various studies have reported that switching between tasks and sets repeatedly is associated with activation in MFG, and therefore it is assumed to be associated with the switching function of the CES (Brass, Derrfuss, Forstmann, & von Cramon, 2005; Brass & von Cramon, 2002; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Sohn, Ursu, Anderson, Stenger, & Carter, 2000). Dual task studies have found that the medial prefrontal areas, including the ACC, are associated with task set maintenance and monitoring, which indicates the updating function in cognitive processing (Dosenbach et al., 2006, 2008; Fleck, Daselaar, Dobbins, & Cabeza, 2006; MacDonald, Cohen, Stenger, & Carter, 2000; Rowe, Hughes, Eckstein, & Owen, 2008). The ACC is also frequently reported to be associated with error execution and task coordination. That means that the ACC may also be associated with the inhibition function because making errors during task processing indicates an inability to inhibit a dominant response that should be suppressed (Carter et al., 1998; Cohen, Botvinick, & Carter, 2000).

Taken together, these identified dual task areas in the contrast are frequently assessed as an indicator of the executive functions i.e. switching, inhibition and updating (Szameitat et al., 2011). Therefore, the current findings, which demonstrated decreased dual task specific activations in high neurotics, may be evidence that the dual-task specific executive functions are involved to a lesser extent.

Moreover, the results showed strong correlations between the neuroticism scores, dual task costs and activation level in the brain when calculated for the whole sample, i.e. across groups. This is not surprising, because in this instance the correlation is mathematically closely related to the t test calculated in the fMRI analysis. However, when the correlation was calculated for each group separately, the result was not significant. One possible reason for such a non-significant correlation is that by creating extreme groups of high and low neurotics, the variance within each group is strongly limited, which therefore makes it hard to detect correlations. In other words, in the small samples, after having a certain EPQ score, the arousal level may influence the related brain areas to a similar degree because the arousal level may rise in all participants to a similar extent (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Because the sample is relatively small for a correlational analysis, small variations between the participants regarding brain activations could not be observed. Thus, the activation differences between an individual who scored 16 and another one who scored 18 on the EPQ scale seem to be affected by the demanding task to a similar degree with slight variations because both are in the top quartile in a small sample and are called high neurotics either regarding sample size (Szymura & Wodniecka, 2003) or EPQ scale (Chan et al., 2007). The same logic is valid for low neurotics because they were selected from the bottom quartile. Individuals scored 5 or 4 on the neuroticism scale, and they probably had similar bold signals with small variations in task processing because the arousal level remained below the activation threshold in the low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Consequently, because the variation in the EPQ scores is too small and the correlation is rather weak, a much bigger sample would be needed to show a significant correlation between neuroticism score, dual task cost and the bold signals.

I observed a similar pattern of dual-task specific activation in the low and high neurotics, which differed only in the strength of the activation, which suggests that the underlying mental operations in both groups are qualitatively similar. It is interesting to note that a recent study found a very similar pattern, i.e. increased behavioural dual-task cost associated with decreased dual-task specific activation in normal healthy controls (Szameitat et al., 2016). Although the authors did not control for neuroticism level in the study, it seems likely that the 17 participants are more clustered around the mean of the EPQ than the sample of the present study, in which I formed two extreme groups (total N = 32) based on an initial screening of more than 700 people. Combining these two findings, i.e. the same pattern of dual-task related brain areas in high and low neurotics and the same gradual relationship between performance and brain activation in normal controls and neurotics, suggests that neuroticism does not alter the neuro-cognitive processing of a dual-task qualitatively, but rather gradually. In other words, the current findings suggest that high neurotics multitask rather comparably to low-performing controls. A potential reason for this may be higher demand on the CES functions due to the existence of a bottleneck and the preparation processes.

This interpretation is in line with the assumed role of these areas in dual task processing. I mentioned above that these areas are associated with the switching, inhibition and updating functions to resolve interference and coordinate task processing. It has been argued that lower activity in these areas indicates less efficient mental processing, and consequently behavioural performance suffers (Brass & von Cramon, 2002; Hartley et al., 2011; Szameitat et al., 2016). This is exactly what neuroticism related models commonly predict as high neurotics are likely to perceive a demanding task (i.e. dual-task) as considerably more stressful than low neurotics, so their arousal levels are increased, which causes higher task irrelevant activities (Derakshan & Eysenck, 2009; H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Therefore, task irrelevant activities interfere with attention, so that in high neurotics attention must be divided for task related and task irrelevant activities, which lead to the allocation of less mental resources to task processing (Derakshan & Eysenck, 2009; M. W. Eysenck & Derakshan, 2011). Because CES functions require greater sustained attention (De Jong, 1995a; M. W. Eysenck et al., 2007; Luria & Meiran, 2005; Miyake et al., 2000), this detrimental effect of neuroticism mainly impairs the CES functions during dual task processing (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). I mentioned in the previous paragraphs that high dual task cost is accompanied by decreased activation in the specific areas that seem to be associated with the three CES functions (switching, inhibition, and updating) (De Jong, 1995a; Stelzel et al., 2008b; Szameitat et al., 2016). This fits well with my previous findings (chapter 2-5), which showed that the main cause of higher task impairment is specifically higher CES demand in high neurotics.

Regarding functional neuroanatomical correlates in neuroticism related group differences; DMC (Braver, 2012) also seems to be approachable for the interpretation of the current results. DMC suggests that higher task irrelevant activities caused by arousal and worry in high neurotics may prevent them from using a proactive control mechanism to employ cognitive resources for efficient task processing because task relevant activities are perceived as a threatening factor for task processing (Braver et al., 2007; Burgess & Braver, 2008; Gray et al., 2002). Therefore, high neurotics are inclined to use a reactive control mechanism, which causes suppression in the cognitive control regions to deal with threatening situations (Braver et al., 2007). Consequently, reduced activation occurs in the cognitive control regions (Braver, 2012; Burgess & Braver, 2008; Gray et al., 2002). This argument is supported by previous empirical studies, which show reduced activation in the cognitive control network regions in high neurotics compared with low neurotics in the processing of WM tasks (Bishop, 2009; Dima et al., 2015). Accordingly, this situation may cause higher costs, which are accompanied by decreased activation due to inefficient employment of cognitive resources during task processing (Bishop et al., 2004; Bishop, 2009).

In conclusion, to my knowledge, this is the first study to explore neuroticism related differences regarding the functional neuroanatomical correlates of dual task processing. I found that high neurotics showed higher behavioral dual-task costs and at the same time lower dual-task specific brain activation compared with low neurotics. I interpret the results as evidence that high level neuroticism causes impairment particularly in higher cognitive functions, such as the functions in dual task processing, located mainly in the lateral and medial prefrontal cortices. The impairment may be caused by an overly increased level of arousal, which leads to greater task irrelevant activities during dual task processing, which are associated with higher demand being placed on the switching, inhibition and updating functions.

7 Chapter – General discussion

7.1 Overview

Neuroticism is a personality trait characterized by an inclination towards negative emotional states and high levels of anxiety (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; Jorm, 1989; Zawadzki et al., 1998). Behavioural studies in the field of cognitive psychology have shown that neuroticism impairs cognitive performance mostly in difficult tasks, but not so much in easier tasks (Corr, 2003; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). One pervasive situation of this type is multitasking, in which the combination of two simple tasks creates a highly demanding dual-task (Logan & Gordon, 2001; Pashler, 1994a), and consequently high neurotics show higher dual-task costs than low neurotics (Studer-Luethi et al., 2012). While the existing data is highly informative, there is a paucity of research about where and how task impairment occurs during cognitive task processing. Therefore, in this thesis, I have investigated neuroticism related group differences during cognitive task processing that mainly included dual task experiments regarding behavioural performance and functional anatomical dual task specific activities in the brain. As a starting point (in chapter 2), I used single standard WM tasks, which tested the effect of neuroticism on both the central executive system (CES) and WM storage system (i.e. visuospatial sketchpad). The remainder of the empirical studies consisted of PRP dual tasks to investigate the specific effect of neuroticism on the CES functions. The purpose of this thesis was to provide a more accurate account of the effect of neuroticism on cognitive task processing both regarding behavioural performance and functional anatomical correlates. More specifically, I explored whether the detrimental effect of neuroticism causes lower processing efficiency in all difficult tasks or whether it is specific to certain tasks associated with the switching, inhibition and updating functions. In chapters 2 and 5, part of the research investigates this issue. In addition, there was a need to control the experiment at a high level to investigate the effect of neuroticism on the CES functions in detail. Therefore, in most of the chapters (3, 4, 5), I used a PRP dual task paradigm to investigate this issue (i.e. the effect of neuroticism on the CES) by increasing the demand specifically on the CES functions. Also, in chapter 5, perceived stress and difficulty level were explored to find out whether arousal level increases as the task demand increases. Finally, in chapter 6 functional anatomical correlates of neuroticism related group differences were investigated during PRP dual task processing.

In all of the empirical chapters, the studies consisted of two stages: screening and testing. The testing stage provides the most important results. Nonetheless, the screening stage determined several exclusion criteria related to the validity and reliability of the results at the testing stage. Therefore, before I discuss the empirical findings, I discuss this issue (i.e. screening) below so I will develop the discussion through the stages respectively.

7.2 Neuroticism scale and selection of study sample

To select high and low neurotics for this study, I used the neuroticism scale of EPQ (H. J. Eysenck & Eysenck, 1975). Although the EPQ is a continuum scale, I used a cut-off based on previous studies to select the high and low neurotic participants (Chan et al., 2007; Di Simplicio et al., 2014; Portella, Harmer, Flint, Cowen, & Goodwin, 2005). Therefore, in this section, I discuss the advantages of using such a cut-off in the EPQ scale to select extreme groups of high and low neurotics instead of just using a median split. Furthermore, I discuss the creation of extreme groups of high and low neurotics using some exclusion criteria.

By using this approach, firstly, I aimed to determine clear differences between the high and low neurotics regarding their behavioural performance and neural correlates during the task processing (Chan et al., 2008; Chan, Norbury, Goodwin, & Harmer, 2009). In contrast to my approach, a few studies have used a median split of the EPQ scale to create groups of high and low neurotics (Osorio et al., 2003). However, this approach does not allow determination of clear differences between high and low neurotics regarding either their behavioural performance or neural correlates during the task processing (Chan et al., 2009). It has been suggested that using a median split does not clearly indicate that the top group is high and the bottom group is low neurotics (Francis et al., 1992) because neuroticism symptoms start with a score of 10 on the EPQ scale (Karanci et al., 2007). Therefore, if I had used the median as a cut-off, in this case an unclear situation would have occurred, because the participants with neurotic symptoms may have been included in low neurotic group. I assumed that this might be a factor that could lead to inconclusive results as in some of the previous studies e.g. (Osorio et al., 2003).

Eysenck (1967) proposed inverted U curves to explain the performance of high and low neurotics. Accordingly, high and low neurotics perform differently during task processing depending on the task difficulty and increased arousal level (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Individuals who score very high on the neuroticism scale perform worse than individuals who score very low on the scale on demanding tasks because in highly neurotic individuals the arousal level easily increases and after it reaches a certain activation threshold their performance is impaired (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Because low neurotics have a higher activation threshold compared to high neurotics, the performance of low neurotics is relatively better than high neurotics in demanding tasks (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). However, a moderate neuroticism level (i.e. a score in middle range of EPQ scale) may follow an optimal arousal level and best performance during moderately demanding tasks (H. J. Eysenck, 1967). Based on this argument, I considered selecting high and low neurotics from the top and bottom quartiles of the neuroticism scale because this method of selection has also been repeatedly applied in previous studies (Chan et al., 2007; Di Simplicio, Norbury, Reinecke, & Harmer, 2014b; Portella et al., 2005; Szymura & Wodniecka, 2003).

Moreover, it can be seen that the cut-off values are not symmetrical (Low N= 0-6, High N= 16-24). Instead of these cut-off scores, one could consider using a more symmetrical cut-off such as Low N= 0-8, High N= 16-24. However, the reason for my preference for the current cut-off values (i.e. Low N= 0-6, High N= 16-24) is that people who score over 10 on the EPQ may show neurotic symptoms and I wanted to determine a cut-off that was relatively far away from 10 for low neurotics. Because my aim was to select extreme groups of high and low neurotics, I considered selecting people who scored very low on the neuroticism scale. In addition, several reliable studies have used these cut-off scores to select high and low neurotics (Chan et al., 2007; Chan et al., 2009; Portella et al., 2005). Therefore, I preferred to select groups of high neurotics (score above 16) and very low neurotics (score below 6). This approach seemed to be plausible, because it would allow for finding clearer differences between the groups (Chan et al., 2007; Portella et al., 2005). Consequently, the selection of high and low neurotics in this way allowed me to obtain reliable and valid results that are consistent with neuroticism related theories that show that high and low neurotic participants differ considerably regarding demanding tasks while they are usually similar in terms of simple task performance (H. J. Eysenck & Eysenck, 1986; M. W. Eysenck et al., 2007).

In addition, another issue was that several studies have randomly recruited high and low neurotics by applying the EPQ only (Corr, 2003; Osorio et al., 2003; Robinson & Tamir, 2005; Szymura & Wodniecka, 2003). This might be another reason why some of these studies remain inconclusive. It has been shown that psychological disorders such as depression also cause some cognitive deficits (Chan et al., 2007; Portella et al., 2005).

Because depressed people usually score higher on the neuroticism scale (Chan et al., 2007; Chan et al., 2009), if a depressive participant is not excluded, one will never know whether the impairment was caused by the effect of depression or neuroticism (Chan et al., 2009). In addition, arousal level may be influenced by caffeine, alcohol or mood state in high neurotics (Chan et al., 2007; Chan et al., 2009). For example, it was found that caffeine may have a greater effect on arousal in high neurotics than low neurotics so the consumption of caffeine may negatively affect performance in high neurotics (Craig et al., 1979). To deal with such issues, which may affect the results, I used several tests as exclusion criteria to recruit the high and low neurotic participants. To that end, I selected two groups that included high neurotics and low neurotics that were not associated with other typical factors that may affect cognitive processing. In other words, I aimed to minimize the contamination effect of other factors such as psychiatric and neurological history; colour blindness; alcohol and caffeine consumption; and recent depressive mood by using related tests. Therefore, the results in this thesis seem to show the effect of neuroticism and are not due to other typical factors indicated above.

In the next section, I discuss the effect of neuroticism on processing efficiency across cognitive tasks. The discussion is developed to answer the question of whether neuroticism affects processing efficiency in all cognitive tasks or whether this effect is revealed only in certain tasks.

7.3 Effect of neuroticism and processing efficiency

Processing efficiency is assessed based on response times and accuracy so a higher processing efficiency refers to performing tasks with faster response times and higher accuracy (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). In this context, lower processing efficiency would indicate actual task impairment (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). This is of particular interest for this thesis in terms of understanding what task impairment is between high and low neurotics. The reason for that is, in most of the experiments, the performance of the participants was measured regarding both response times and error rates. For example, sometimes the participants performed certain tasks with a faster response time and lower accuracy or vice versa. This type of observation does not usually indicate a better processing efficiency; rather it indicates they may use different speed accuracy trade-off strategies (M. W. Eysenck et al., 2007; Flehmig et al., 2010). In addition, it was noted that sometimes the response time was considerably shorter in one group but the error rates did not significantly differ between the groups (M.

W. Eysenck et al., 2007). In such a situation, the group with considerably shorter response times has better processing efficiency (Derakshan & Eysenck, 2009; Flehmig et al., 2010).

Based on the argument above, the high neurotics had lower processing efficiency in the IED (chapter 2) set shifting task and dual task performance (chapter 3-6) compared with the low neurotics. In particular, in the dual tasks, the high neurotics had lower processing efficiency as the demand increased on the CES functions. This was always evident in their slower response times and usually the execution of a higher number of errors. However, the high and low neurotics did not differ in the single tasks (in dual task studies), SWM task and SOC tasks. In addition, the neuroticism related group differences were not influenced by the task difficulty in terms of stimuli degradation in the dual task. These results were evident from the similar response times and error rates.

It should be noted that in the single tasks (chapter 3-5) and SOC task (chapter 2) performance, high and low neurotics may use different speed accuracy criterion. Therefore, despite the non-significant results, numerically, sometimes the high neurotics seem to have lower accuracy or faster response times. For example, the high neurotics, numerically, had faster RTs and lower accuracy than the low neurotics in the SOC task performance in chapter 2. Also, in long SOA dual tasks, high neurotics were had slower RTs and numerically had higher accuracy than low neurotics. Such results are at least partially due to a different speed accuracy strategy (Flehmig et al., 2010). However, in chapter 3, because the task demand was considerably higher on the CES functions in short SOA dual tasks, the high neurotics were slower and had a higher number of errors so the effect of neuroticism clearly cannot be explained by the groups using different speed accuracy strategies. Easterbrook (1959) suggests that if a task is not demanding enough, high neurotics may narrow their attention either to response times or accuracy. Therefore, they may be observed to have either faster response times or higher accuracy (Szymura & Wodniecka, 2003) but they cannot become better in terms of both response times and accuracy, which indicates higher processing efficiency (M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007; Flehmig et al., 2010; Szymura & Wodniecka, 2003).

Taken together, the results indicate that the high neurotics had lower processing efficiency than low neurotics in the IED set shifting task and dual tasks. However, neuroticism related group differences did not influence certain standard WM tasks, the SWM and SOC tasks. In addition, neuroticism related group differences did not influence single task processing and task difficulty by stimuli degradation in the dual task. The results indicate that the detrimental effect of neuroticism may impair only certain tasks and not all cognitive tasks (M. W. Eysenck et al., 2007). In the next sections, I discuss the reason why a high level of neuroticism impairs only certain tasks.

7.3.1 Does the effect of neuroticism cause lower processing efficiency in all difficult cognitive tasks?

The arousal based theory of Eysenck (1967) suggests that high neurotics perform worse than low neurotics in difficult tasks whereas they perform similarly on easy tasks because task difficulty causes worry related increased arousal level, which impairs task processing. However, what is meant by term 'difficult task' is not clearly explained. The question of interest then is whether the detrimental effect of neuroticism impairs performance in all difficult tasks? For example, a cognitive task could be difficult due to increasing the demand in the VSSP i.e. a SWM task or it could be difficult at a perceptual level in dual task performance i.e. due to stimuli degradation.

In contrast, attentional control theory (ACT) (M. W. Eysenck et al., 2007), which evolved from PET (M. W. Eysenck & Calvo, 1992), proposes detailed assumptions about task impairment due to worry related increased arousal. It has been suggested that the detrimental effect of neuroticism impairs the three CES functions, i.e. switching, inhibition and updating, during demanding task processing whereas it does not have a significant influence on the storage systems of WM (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). The reason for that is that a worry related increased arousal level causes task irrelevant activities (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Therefore, high neurotics must deal with task related activities as well as task irrelevant activities (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Because the three CES functions require the highest sustained attention for efficient task processing, increasing task irrelevant activities limits the investment of efficient mental effort in these functions (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). However, empirical studies testing this assumption are sparse in relation to showing the effect of neuroticism on cognitive processing. In these studies, the effect of neuroticism is usually tested in dual tasks, which are a combination of two standard WM tasks e.g. (Corr, 2003; Poposki et al., 2009; Studer-Luethi et al., 2012; Szymura & Wodniecka, 2003). These studies usually conclude that high neuroticism impairs WM demand (Poposki et al., 2009; Studer-Luethi et al., 2012) and do not provide specific knowledge about the effect of neuroticism on the switching, inhibition and updating functions. It was therefore important to conduct a study that circumvents such arguments and resolves this issue. Therefore, some of results in chapter 2 (i.e. SWM), and chapter 5 (stimuli degradation in dual task) shed light on this issue.

In chapter 2, I found that high neurotics had greater task impairment in a demanding task that required extensive use of the switching and inhibition functions, i.e. WSCT. However, the results showed that the high and low neurotics did not differ in any conditions of the SWM tasks that demanded the VSSP. The results seem to be in line with ACT, which proposes that the detrimental effect of neuroticism does not influence the VSSP, because neutral visuospatial representations are not involved in inner words activities which associate with worry (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011).

Furthermore, in the dual task chapters (3-6), I found that generally the high neurotics had higher dual task costs (i.e. slower responses and lower accuracy) than the low neurotics, which indicates lower processing efficiency as the demand increases on the CES functions. Also, in chapter 5, a part of the study consisted of two versions of three choice dual tasks. In one dual task the stimuli degraded and in the other the identical stimuli were non-degraded. These two versions of the dual tasks were identical so that the demands on the CES functions were not varied because it has been found that stimuli degradation is not associated with WM demand (Barch et al., 1997). The results showed that both the high and low neurotics had higher dual task costs and PRP effect in the degraded version compared with the non-degraded version of the dual task. That indicates that the degraded task was more difficult than the non-degraded task. However, the differences in the DT-costs between the high and low neurotics were similar in the degraded and non-degraded dual tasks. If the task difficulty causes a higher impairment in high neurotics compared to low neurotics, the cost differences between the groups will be larger in a dual task with degraded stimuli. It seems that neuroticism related group differences do not influence this type of task difficulty. The potential reason for that is, in dual task studies two tasks can be handled in parallel during perceptual and motor stages, whereas in response selection stage each task can be handled one by one (Marois & Ivanoff, 2005; Pashler, 1994a; Sigman & Dehaene, 2005). Therefore, because the perceptual stage is not associated with the executive functions (Dux et al., 2006), high neuroticism does not impair task processing, even if the task demand is increased at the perceptual stage. Therefore, the result seems to be in line with the assumption of ACT (M. W. Eysenck et al., 2007) again. However, in this assumption, task impairment is assessed in the scope of WM by suggesting that neuroticism impairs the CES functions but not the storage systems (M. W. Eysenck et al., 2007). Previously, I highlighted that task difficulty by degrading stimuli is disassociated from WM demand (Barch et al., 1997). Therefore, this is a new contribution that shows that task difficulty, which is disassociated from WM demand, may not be associated with the effect of neuroticism in task processing.

In this thesis, a few tasks such as the SOC tasks and long SOA tasks with 2 S-R loads might not have been sufficiently difficult in terms of the CES demand. The demand on the CES functions is important because the related arousal level increases easily in high neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). For example, the SOC (chapter 2) task and two choice dual tasks with a long SOA (chapter 3-5) are both associated with the CES functions. However they may not have been demanding enough to trigger an arousal level that exceeded the activation threshold. My interpretation regarding the performance of these tasks is that the task demand was not high enough. For example, I mentioned that the SOC task is associated with inhibition functions under the two and three moves conditions (Miyake et al., 2000; Ozonoff et al., 2004). However when task demand increases to the four and five moves conditions, it is associated with the planning function (Ozonoff et al., 2004). Consequently, because the demand on the inhibition function remained lower, the arousal level did not exceed the activation threshold in the high neurotics and thus the high and low neurotics did not differ in terms of task performance. Similarly, in the two choice dual tasks with a long SOA, the task demand on the CES functions was lowered by 1000 ms SOA (Luria & Meiran, 2005). Therefore, the high and low neurotics showed little difference in terms of the task processing. This interpretation fits well with the theoretical accounts, because the arousal based theory of neuroticism (H. J. Eysenck, 1967) and ACT (M. W. Eysenck et al., 2007) states that a cognitive task should be optimally demanding to increase the worry related arousal level in high neurotics and therefore impair task processing (Corr, 2003; M. W. Eysenck et al., 2007). This is quite important because a task may be associated with the CES functions but if it is not demanding enough to increase the arousal level, the task processing may not be impaired (H. J. Eysenck, 1967; M. W. Eysenck et al., 2007).

Taken together, I propose that the effect of neuroticism does not impair task processing in all difficult tasks. Therefore, the arousal based theory of neuroticism could be valid for certain tasks associated with the CES functions. The results seem to be consistent with ACT because the high neurotics had lower processing efficiency than the low neurotics in demanding tasks that required extensive use of the CES functions. However, when the task was simple and not associated with the three CES functions i.e. it was associated with the storage systems or another CES function, the high and low neurotics often perform similarly (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). Consequently, these findings corroborate my hypotheses, which indicate that high neurotics perform considerably worse than low neurotics in demanding tasks associated with the switching, inhibition and updating functions whereas they perform similarly on tasks dissociated from the CES demand (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007).

To conclude the discussion in section 7.3, two important factors are necessary to reveal the detrimental effect of neuroticism. First, the task should be associated with the switching, inhibition and updating functions (M. W. Eysenck et al., 2007). Second, the demand should be high enough to increase the worry related arousal level and therefore cause higher task irrelevant activities and task impairment (H. J. Eysenck, 1967). In the next section, I discuss the effect of neuroticism on the CES function across standard WM tasks and dual task performance in high and low neurotics.

7.4 Effect of high neuroticism level on CES functions

Collectively, the results reported in this thesis make several novel and important contributions that advance our understanding of the effect of neuroticism on the CES functions during cognitive task processing. Probably, the most novel results were provided by the dual task studies. Because I have already discussed chapter 2 in the previous section, I will only discuss the implications briefly that are related to this chapter, which leads me to the design of the PRP dual task studies.

7.4.1 Effect of neuroticism on standard WM tasks performance

The main implication of chapter 2 is that a high level of neuroticism may impair the CES functions whereas it seems to have no influence on the VSSP demand. Moreover, even if a task is associated with one of the three CES functions, high neuroticism may not impair task processing because the task may not be demanding enough in terms of the three main functions. These findings provided a guide for the next experimental paradigms. To my knowledge, this is the first study conducted with single standard WM tasks to specifically investigate the effect of neuroticism level on the CES functions.

These findings can act as a guide for possible future studies. Thus as ACT (M. W. Eysenck et al., 2007) suggests, the experimental design for future studies should involve the switching, inhibition and updating functions. In addition, it has been suggested that when a task requires divided attention this will lead to greater demand on these functions (Baddeley, 1996a; Della Sala et al., 1995) and thus high neurotics will show impaired task processing compared to low neurotics. Taken together, these descriptions in terms of task processing that involves the switching, inhibition and updating functions of the CES and requires divided attention fit well with the PRP dual task paradigm (Szameitat et al., 2016).

In the next section, I discuss the findings of the dual task experiments. Because I manipulated the task demand on the CES functions using task coordination and task set maintenance, I discuss this in two subsections: dual task coordination and dual task set maintenance.

7.4.2 Effect of neuroticism on dual task performance

Eysenck et al. (2007) indicate that there is a paucity of dual task studies relating the effect of neuroticism to CES functions and that this limitation is preventing us from making precise predictions about the detrimental effect of neuroticism on dual task processing. Therefore, it has been suggested that dual task studies of extremely important to investigate the effect of neuroticism on cognitive processing (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). The reason for that is that dual task paradigms may provide new insights into where and how the impairments occur during demanding task processing in high neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007). The current findings seem to corroborate this theory through the employment of a PRP dual task paradigm in relation to the effect of neuroticism on the switching, inhibition and updating functions.

PRP dual tasks can be designed to manipulate task order coordination (De Jong, 1995b; Luria & Meiran, 2003; Szameitat et al., 2002) and task set maintenance (Stelzel et al., 2008b), and thus the strength of the demand can be manipulated differently on the CES functions (Stelzel et al., 2008b; Szameitat et al., 2002). These advantages allowed for testing my predictions about the effect of neuroticism on the switching, inhibition and updating functions during task processing in depth.

7.4.2.1 Effect of neuroticism in dual task coordination

As I mentioned in the literature review chapter, task order coordination is one of the most prominent mechanisms that distinguishes the processing of dual tasks from single tasks (De Jong, 1995b; Luria & Meiran, 2005; Stelzel et al., 2008b). Thus, it is needed when two tasks compete in the capacity limited stage called bottleneck processing (Jiang, 2004; Marois & Ivanoff, 2005; Szameitat et al., 2016). In short SOA tasks and in random order dual tasks, task competition increases and a greater dual task cost is revealed (De Jong, 1995b; Jiang, 2004; Luria & Meiran, 2005; Mayer, 1977; Pashler, 1994a). In such situations, participants require better switching, inhibition and updating functions to successfully achieve the task processing (De Jong, 1995b; Luria & Meiran, 2005; Szameitat et al., 2016). Based on this information, to explore the effect of neuroticism on switching, inhibition and updating, the first dual task experiment (chapter 3) involved task order coordination.

First, I increased the task demand from a single task to a dual task because the single task did not require much in terms of the CES functions and the dual task required extensive use of the CES functions (De Jong, 1995b; Szameitat et al., 2016). For example, the participants were required to switch the focus of the bottleneck from the first task to the second task (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). Similarly, they required the inhibition function to avoid the second task until the first task had been processed in the bottleneck (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005; Szameitat et al., 2016). Also, the task processing involved the updating function because they needed to maintain task related orders and other stimuli content (Cowan, 1999; Miller, 2000; Stelzel et al., 2008b). Based on this argument, the results show that the high neurotics had a higher impairment in the dual task processing compared to the single task than the low neurotics. I argue the potential reason for this is that high-level neuroticism may impair the CES functions in bottleneck processing because when performing two tasks simultaneously, the two tasks can only be processed one at a time in the response selection stage (Dux et al., 2006; Marois & Ivanoff, 2005; Sigman & Dehaene, 2005).

It has been suggested that the insertion of additional stimuli may increase the demand on the storage systems of WM (Szameitat et al., 2002). Although I confirmed that a high neuroticism level is not associated with demand on the VSSP, ACT (M. W. Eysenck et al., 2007) proposes that demand in the phonological loop may partly impair task processing because this storage system may be associated with inner words, which are related to worry. Therefore, one way to see the direct effect of neuroticism on the CES functions is by increasing the task demand without the insertion of additional stimuli. Based on this argument, increasing the task demand through SOA manipulation is one way to increase the demand on the CES functions (Luria & Meiran, 2005). It has been suggested that a greater dual task cost can be observed by setting the SOA to 0 whereas increasing the SOA to 1000 ms will reduce the dual task cost to the minimum level in normal healthy people (Logan & Gordon, 2001; Pashler, 1994a). In other words, processing of short SOA involves a higher demand on the switching, inhibition and updating functions (Luria & Meiran, 2003; Luria & Meiran, 2005). In this situation, the task processing is prolonged mainly due to the existence of the bottleneck (i.e. increased RT2 at short SOA, which refers to the second task waiting at the bottleneck stage) (Pashler, 1993; Pashler et al., 2001). In addition, in short SOA task processing, there is no time for the preparation process, which leads to considerable demand on the CES functions (De Jong, 1993; Luria & Meiran, 2005; Szameitat et al., 2016). However, in long SOA tasks, there is more time so the participants typically get the second stimulus only after they have responded to the first stimulus. Thus, the demand on the bottleneck is considerably reduced (De Jong, 1993; Luria & Meiran, 2005; Szameitat et al., 2016). In this context, there is higher demand on the CES functions (switching, inhibition) in the response selection during short SOA tasks than long SOA tasks (De Jong, 1993; Luria & Meiran, 2005; Szameitat et al., 2016).

With respect to neuroticism related group differences, the results showed that the high neurotics had higher dual task RTs costs in the short SOA task compared to the long SOA task, as is evident from the higher dual task combination costs and PRP effect. However, the results regarding the error rates in the high and low neurotics were comparable and did not differ significantly. This situation still indicates that the high neurotics had lower processing efficiency than the low neurotics because in terms of the response times the high neurotics were considerably slower whereas in terms of the error rates the high neurotics had very slightly lower error rates, which was not significant at all (Flehmig et al., 2010). It has been suggested in dual tasks that the task order be prepared automatically (De Jong, 1993; De Jong, 1995b; Luria & Meiran, 2003). This automaticity may lead to some benefits regarding task performance in fixed dual tasks (De Jong, 1993; De Jong, 1995b; Luria & Meiran, 2003). This is because in a fixed dual task, the order of the tasks does not change; when the first task comes, the second task is prepared automatically (e.g. DT-AV, then “A” is prepared for the next trial) (De Jong, 1993; De Jong, 1995b; Luria & Meiran, 2003). Based on this argument, high neurotics may narrow their attention to task accuracy (Easterbrook, 1959; Flehmig et al., 2010; Szymura & Wodniecka, 2003) and therefore they may get more benefit from that automaticity in dual task processing. However, because of the detrimental effect of neuroticism, which considerably impairs task processing, they cannot compensate for the higher impairment due to task irrelevant activities (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011).

Moreover, to maximize the demand on the three CES functions, I created a random dual task to be performed by the high and low neurotics. The distinctive feature of this condition was that it was another way to increase the demand on the CES functions without the insertion of another stimulus (De Jong, 1995b; Szameitat et al., 2002) and it was rather more demanding than the fixed dual task (De Jong, 1995b; Luria & Meiran, 2005). While in the fixed dual task conditions the participants performed the component tasks in a constant order (e.g., A-V, A-V, A-V, etc.), in the random dual task the participants had to perform the tasks in a randomly changing order (e.g. A-V, V-A, V-A, A-V, etc.) (De Jong, 1995b; Szameitat et al., 2002). Therefore, in this condition, the participants could not get any benefit from the task being set automatically (De Jong, 1995b; Luria & Meiran, 2005). In detail, in the random task, sometimes the task order was repeated and sometimes it was switched (De Jong, 1995b; Luria & Meiran, 2005). It has been suggested that the bottleneck mechanism is automatically set, i.e. prepared, for the task that came first in the last trial (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005). Therefore, when the task order is altered in the present trial, a wrong task will be prepared in the bottleneck and this must be altered again to set the correct task (De Jong, 1993; De Jong, 1995b). For example, in the switching trials, the stimuli presentation was visual =>auditory and then auditory=>visual. In this case, when the trial was switched, the visual condition would have been set in the bottleneck because the second task from the previous order was the visual task. Therefore, this had to be switched once more to set the auditory task (Luria & Meiran, 2005). This switching may involve inhibition of the task and an update of the S-R mapping (De Jong, 1995b; Luria & Meiran, 2003; Luria & Meiran, 2005). It has been noted that the highest demand is on the switching and inhibition functions rather than the updating function (De Jong, 1995b) because the number of stimuli and responses that involve the updating function is always identical as in the fixed dual tasks.

The results showed that the high neurotics had a considerably higher impairment than the low neurotics in the switching trials compared with the repeated trials both regarding the response times and the error rates. The results are quite important in that they show an effect of neuroticism mainly on the switching and inhibition functions. Because the task demand was quite high compared to the single tasks and fixed dual tasks, the worry related arousal level was considerably increased in the random dual task condition. Therefore, a lower processing efficiency was observed in the high neurotics compared with the low neurotics. The task was demanding for the low neurotics as well because they had a higher response time and lower accuracy compared to the repeated trials. However, the worry related arousal level may not have exceeded the activation threshold as in the high neurotics because low neurotics have a higher activation arousal threshold.

In addition to slower RTs, the high neurotics had a significantly higher number of errors compared with the low neurotics. These results support my interpretation regarding the comparable error rates in the fixed dual task in high and low neurotics (i.e. getting higher benefit from automaticity in the fixed dual task by narrowing attention to accuracy). In the switching trials, because the benefit of automaticity was removed, using a different speed accuracy criterion i.e. narrowing attention to either accuracy or speed, did not work and thus they made more errors as well.

So far, I have discussed how high level neuroticism impairs the switching, inhibition and updating functions either in IED set shifting or dual task processing. In particular, I have demonstrated that the high neurotics had a higher dual task cost than the low neurotics as the demand increased mainly on the switching and inhibition functions. The reason for that is that while the task demand increased progressively on the switching and inhibition functions due to the SOA and task order manipulations, the demand on the updating function remained constant i.e. they were always two 2-choice response tasks with the same stimuli. The findings are consistent with ACT (M. W. Eysenck et al., 2007), which predicts that high neurotics will have lower processing efficiency than low neurotics as the demand increases on the CES functions because the worry related arousal level causes task irrelevant activities and these in turn limit the investment of efficient mental effort in the task (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011).

However, these findings from the dual task need to be replicated by using non-emotional stimuli in a dual task (chapter 4). The reason for that is that in the dual task I used male and female faces for the visual task and syllables for the auditory task. Although these stimuli were not selected intentionally to be emotional and they are actually rather neutral, they still may include some social components that may influence arousal level in high neurotics. It has been suggested that using emotional stimuli (i.e. happy or sad faces) may cause slower RTs due to attentional bias in high neurotics (M. W. Eysenck et al., 2007; MacLeod & Rutherford, 1992; Mogg et al., 1993). It has also been suggested that emotional stimuli such as negative faces may trigger worry that may in turn cause an increase in arousal level (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967; M. W. Eysenck et al., 2007). In addition, it should be noted that according to Eysenck et al., (2007) main cause of task impairment due to emotional stimuli is selective attention toward negative stimuli in high neurotics. Because high neurotics cannot disengage from negative emotional stimuli, they had slower RTs in the related tasks (Canli et al., 2001; Chan et al., 2009). Therefore, to confirm that the results in the dual task are really due to a higher demand on the CES functions, which increases the worry related arousal level, I conducted a dual task study with non-emotional stimuli. The results were very similar to the previous dual task, which showed that the high neurotics had both higher dual tasks costs and PRP effect. Therefore, I interpret these findings as meaning that the higher task impairment in high neurotics is caused by higher task demand on the CES functions and it is not associated with any effect of potential emotional stimuli (M. W. Eysenck & Derakshan, 2011).

So far, in the current section, I have discussed the effect of neuroticism on the dual task coordination. To reinforce these findings, in chapter 5, I asked whether the demand on the CES functions is specific to task coordination which generally higher proportion of the task demand was associated with switching and inhibition functions and the demand on updating relatively remained constant. What if I increased the task demand on the three CES functions in a different way such as by task set maintenance? In the next section, I discuss the effect of neuroticism on the CES functions by using a different manipulation called dual task set maintenance.

7.4.2.2 Effect of neuroticism on task set maintenance

The manipulation in the dual task coordination showed that high neurotics seem to suffer due to demand mainly on the switching and inhibition functions. However, another question of interest is whether, if we place demand on the central executive system by manipulation using task set maintenance, likewise, does this lead to a much higher dual task cost in high neurotics? To test the effect of neuroticism on task set maintenance, I increased the S-R mapping in the dual tasks from two to three and four choices. The S-R mapping was increased only in the visual tasks because increasing the S-R mapping in an auditory task (i.e. phonological loop) may influence task processing (M. W. Eysenck et al., 2007). In this section, increasing the demand by S-R mapping manipulation is named the S-R load. Also, in this study, the dual tasks were presented with two SOA (short and long SOA) as before. Below, as a reminder, first I give a brief summary of the results and then I discuss the effect of the S-R load in high and low neurotics in the long and short SOA tasks respectively.

The results confirmed the previous findings (chapters 3 and 4) by showing that the high neurotics had a higher dual task cost than the low neurotics for all of the numbers of the S-R mappings (S-R load). In addition, the results show a higher difference in the DT-costs between the high and low neurotics as the demand increases due to the S-R load (from 2 to 3 to 4) in the long SOA tasks. In detail, the difference in the DT-costs between the high and low neurotics becomes larger as the demand increases in the long SOA task. Although the high neurotics were still considerably slower than the low neurotics in the short SOA tasks, the difference in the DT-costs between the high and low neurotics remained similar as the demand increased due to S-R load manipulation regarding the short SOA and the PRP effect.

It has been suggested that task set maintenance via manipulation of the S-R load is associated with the response selection stage, which is the center of decisional processes related to the executive functions (Allain et al., 2004; Bunge et al., 2000; Hegarty et al., 2000; Stelzel et al., 2008b; Szmalec et al., 2005). Therefore, increasing the S-R load is associated with the central executive system (Szmalec et al., 2005) and causes a higher dual task cost during the task processing such as manipulation in the task order coordination (Stelzel et al., 2008b). However, the strength of the demand on the three CES functions changes in the S-R load manipulation compared to manipulation in the task order coordination (Stelzel et al., 2008b). Previously, I indicated that in a random task order, the demand is associated more with the switching and inhibition functions and less with the updating in the bottleneck. However, in task set maintenance (increasing S-R load) a higher proportion of the demand is placed on the updating function as well (Allain et al., 2004; Stelzel et al., 2008a) in addition to the demand on the switching and inhibition functions (De Jong, 1995b; Luria & Meiran, 2003). The reason for that is that the two choice dual task processing is associated with the inhibition, switching and updating functions (De Jong, 1995b; Luria & Meiran, 2003). Thus, if the task demand is increased in terms of the S-R load from two to three and four choice dual tasks, the task demand on the updating function considerably increases because more stimuli and response sets should be updated as the load increases (Stelzel et al., 2008b). Likewise, this manipulation naturally places a demand on the switching and inhibition functions as well because a higher number of stimuli and response sets must be shifted and inhibited in the response selection stage when needed during the dual task processing (Szmalec et al., 2005).

Based on the argument above, both the high and low neurotics showed increased performance decrements (slower RTs and lower accuracy) as the S-R load increased. However these decrements were more pronounced in the high neurotics as the S-R load increased in the long SOA tasks. Therefore, the difference in the DT-costs between the high and low neurotics became larger with a higher S-R load because high level neuroticism impairs the three CES functions during task processing. Increasing demand on the updating function, like the demand on the switching and inhibition functions, causes a higher impairment in high neurotics compared to low neurotics (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011)

One reason for this observation in long SOA tasks with an increasing S-R load might be that in this dual task condition, compared to the short SOA, there is some time for preparation to implement the switching, inhibition and updating functions in the second task (De Jong, 1993; Herath et al., 2001; Luria & Meiran, 2005). However, it seems that the increasing S-R load is quite demanding for high neurotics even with 1000ms SOA. Therefore, when the S-R load is increased, 1000 ms SOA might not be a sufficiently enough time to deal with task irrelevant activities for high neurotics. Because the arousal activation threshold is lower in high neurotics compared to low neurotics, a worry related increased arousal level leads to higher task irrelevant activities, which then in turn limit the cognitive resources invested in high neurotics (M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). Because the arousal level activation threshold is higher in low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967), they might not have such increased task irrelevant activities (M. W. Eysenck et al., 2007) so they can benefit from the long SOA in implementing the three CES functions more than high neurotics. Consequently, the high neurotics had lower processing efficiency as the S-R load increased compared with the low neurotics in the long SOA tasks (M. W. Eysenck et al., 2007).

The results regarding the short SOA tasks demonstrated that the high neurotics had higher dual task costs than the low neurotics in all of the S-R loads. For the short SOA, the effect of the S-R load manipulation on the dual-task cost was the same for the high and low neurotics. This means that although the high neurotics always had higher DT costs than the low neurotics, the difference in the DT-costs between the high and low neurotics always remained similar as the S-R load increased. The potential reason for this discrepancy is that the task may have been very demanding for both the high and low neurotics (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967) because the tasks demand increased in two ways, S-R load manipulation and SOA manipulation. Therefore, the limited resources of the cognitive system were easily impoverished in both groups (Bishop, 2009) and thus the differences between the high and low neurotics regarding the dual task costs remained constant (H. J. Eysenck, 1967).

These results confirm ACT (M. W. Eysenck et al., 2007) in terms of the detrimental effect of neuroticism impairing the CES functions. In particular, I confirmed that a higher proportion of demand on the updating function impairs task processing in high neurotics (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). However, ACT (M. W. Eysenck et al., 2007) does not assess the extent to which high neurotics have a higher impairment than low neurotics. The results showed that neuroticism related group differences are to a certain extent influenced by increasing demand on the CES functions. More specifically, when the task became very difficult regarding the demand on the CES functions, the S-R load manipulation affected both groups in the same way (at short SOA). The potential reason for that is limited capacity in bottleneck processing (Marois & Ivanoff, 2005; Sigman & Dehaene, 2005). If a task is highly demanding and exceeds the capacity, the difference between the groups remains constant because the worry related increased arousal level exceeds the activation threshold in both groups (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967).

Regarding the interaction between the increasing arousal level and performance, the results fit well with the U-shaped function, i.e. performance is optimal at an intermediate level of arousal and deteriorates if arousal becomes too high or too low (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). High neuroticism results in a lower arousal activation threshold (Eysenck, 1967), so the inverted U-shaped function is skewed to the left, i.e. in the direction of lower arousal. Translating this into the current results, in the long SOA tasks, the high neurotics became considerably slower than the low neurotics as the demand increased via S-R load manipulation because the tasks were difficult for the high neurotics and therefore their arousal level increased to exceed the activation threshold, which resulted in deteriorated performance. For the low neurotics, the task might not have been as difficult as it was for the high neurotics. Their arousal level may have remained below the activation threshold because the low neurotics have a higher activation threshold for arousal (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Finally, the differences between the high and low neurotics regarding the dual task cost and PRP effects remained constant across all of the short SOA tasks. The reason for that is that both the high and low neurotics felt that the task was extremely difficult so the arousal level exceed their activation threshold in both groups (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967). Therefore, in both high and low neurotics, a worry related increased arousal level limits investing efficient mental effort into a task (Bishop, 2007; Bishop, 2009).

In the next section, I discuss the scores for perceived stress and difficulty level in the high and low neurotics in terms of the task difficulty across the dual tasks in chapter 5. I discuss whether any increase in task demand with increased perceptual difficulty affected the high and low neurotics differently, or whether this was specific to increased demand on the CES functions. The discussion is based on the perceived stress and difficulty scores in the high and low neurotics as an indication of higher arousal in dual task performance (chapter 5) (H. J. Eysenck, 1967).

7.4.3 Does increased arousal level always impair demanding task processing?

The neuroticism related theories (ACT (M. W. Eysenck et al., 2007), PET (M. W. Eysenck & Calvo, 1992), arousal based theory of neuroticism (H. J. Eysenck, 1967) are all agreed that the main cause of task impairment is a worry related increased arousal level. It has been suggested that as an indication of a higher level arousal, high neurotics often score higher on stress and difficulty in subjective measures (e.g. questions that measure perceived stress level and difficulty) compared with low neurotics (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). Empirical studies have confirmed this prediction by showing that high neurotics report higher perceived stress and difficulty in subjective measures following dual task performance (Poposki et al., 2009). However, the findings of this report did not provide information about whether the high neurotics reported a higher perceived stress and difficulty level in relation to the demand on the CES functions and other task difficulty disassociated from the CES. To rectify this issue, in chapter 5, after the experiment had been completed, the participants completed a questionnaire that asked them how stressful and difficult they felt each task had been. The results showed that the high and low neurotics experienced similar stress and difficulty in the single task processing. Furthermore, as soon as the task demand increased via S-R load manipulation or stimuli degradation, the high neurotics perceived higher stress and difficulty compared to the low neurotics. These results confirm my hypothesis regarding perceived stress and difficulty in high neurotics compared with low neurotics during task performance.

In the single tasks, the perceived stress level and task performance differences between the groups were similar because the task was easy so the arousal level did not increase in the high neurotics or the low neurotics. Combining these two findings, the results fit well with the neuroticism related theories (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). They all predict that if a single task is easy (H. J. Eysenck, 1967) or does not require much in the way of the CES functions (M. W. Eysenck et al., 2007), the arousal level does not increase in either groups so the task performance is similar in both groups (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007).

Moreover, the perceived stress and difficulty differences between the high and low neurotics became larger as the demand increased due to the S-R load manipulation. This was similar to the graph in chapter 5 (figure 5.5), which shows the cost differences between the high and low neurotics in the long SOA tasks. In other words, the differences between the groups regarding perceived stress level and dual task cost became larger in parallel as the task demand increased via the S-R load manipulation. These results corroborate the hypothesis that suggests that a difficulty increase in the CES functions causes a worry related arousal level increase (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007).

Interestingly, this (i.e. the argument in the above paragraph) was not the case regarding increasing the task difficulty by stimuli degradation. In detail, the high neurotics perceived considerably higher stress and difficulty than the low neurotics as the task demand increased from a non-degraded dual task to a degraded one. Despite this situation, regarding task performance, the dual task cost differences between the high and low neurotics did not differ. It should be noted that the dual tasks were identical so the tasks were equally demand regarding the CES functions except for the stimuli degradation in the difficult task, which was disassociated from WM demand (Barch et al., 1997). In this case, because the high neurotics might have had a higher arousal level as the demand increased (H. J. Eysenck & Eysenck, 1986; H. J. Eysenck, 1967), in the dual task with degraded stimuli the cost differences would have been larger than the dual task with non-degraded stimuli. However, the dual task cost differences between the high and low neurotics remained similar in both dual tasks. Thus, a higher arousal level due to stimuli degradation did not influence the neuroticism related group differences by causing an additional impairment in the CES functions in the dual task with degraded stimuli.

According to Eysenck et al., (2007) stressful and difficult conditions that are not threat related stimuli (e.g. negative emotional images or videos) may not lead to task irrelevant activities because these conditions may not associate with worry related increased arousal. Although it has been suggested that it is difficult to interpret such a statement without sufficient empirical data (M. W. Eysenck et al., 2007), it has been indicated in an unpublished study by Eysenck and Santos (2006) that despite higher perceived difficulty scores in high neurotics, high and low neurotics do not differ clearly in stressful conditions compared with non-stressful conditions that are not associated with the WM demand and emotionality in dual task. In detail, according to ACT (M. W. Eysenck et al., 2007), there are two ways in which higher task impairment is caused in high neurotics: through increasing the CES demand and through the insertion of an emotional stimulus into the tasks that are associated with the CES functions. The reason why negative emotional stimuli causes higher task impairment in high neurotics compared with low neurotics is because selective attention toward negative emotional stimuli associates with worry which lead disengagement from the stimuli in high neurotics (Chan et al., 2007; M. W. Eysenck et al., 2007; Haas et al., 2007). Therefore high neurotics become slower during task processing (Canli et al., 2001; M. W. Eysenck et al., 2007). However, the stimuli degradation in our dual task was not associated with either CES demand or emotional stimuli. Therefore, one possible reason for this result might be that the degraded stimuli were neutral and did not contain any emotional valence so this type of perceptual difficulty was not associated with the worry related arousal level that causes task irrelevant activities. In addition, one study conducted a series of experiments to shed light on whether the detrimental effect of neuroticism impairs only CES functions when task difficulty increases in regard to either the CES or VSSP (M. W. Eysenck et al., 2005). It has been reported that if one of the tasks involves the central executive system (i.e. dual task A: Corsi block and WCST) in dual task performance, high neurotics show higher task impairment compared with when the dual task consists of two tasks that are associated with the slave systems (i.e. dual task B: corsi block and articulatory suppression) during dual task processing (M. W. Eysenck et al., 2005). Also, in both dual tasks A and B, the task difficulty is increased in Corsi block task. It has been found high and low neurotics do not differ as the load increase when demand increase in VSSP. However, when task difficulty increase in WCST (CES demand), high and low neurotics considerably differ as the difficulty increase. It should be noted that performing two tasks in a rapid succession is known to be associated with CES functions (Baddeley et al., 2011; Baddeley, 1996a; Della Sala et al., 1995). Based on this view, the results indicates when task demand increase out of the CES in the dual tasks, the cost differences between high and low neurotics do not become larger (no significant interaction effects). Although in this study (M. W. Eysenck et al., 2005), perceived stress and difficulty scores has not been investigated, in high and low neurotics, it seems to be in support of the current results in dual task with degraded stimuli. Consequently, it seems the effect of increasing perceptual task demand in dual tasks (which is not associates with CES) is not affected by neuroticism.

The results also fit well with the PRP dual task paradigm. It has been suggested that two tasks can be processed in parallel in the perceptual stage during dual task processing. Because degraded stimuli are associated with the perceptual stage, despite the higher difficulty caused by degradation, the cost difference in high and low neurotics does not increase compared to non-degraded DT tasks.

Taken together, the high neurotics reported higher perceived stress and difficulty compared with the low neurotics as the task demand was increased either by S-R loading manipulation or stimuli degradation. The increased perceived stress and difficulty and dual task performance differences between the high and low neurotics were in parallel. In other words, as the demand increased the dual task cost and perceived stress levels increased in high neurotics compared with low neurotics in the S-R loading manipulation. The results confirm neuroticism related theories in so much as when arousal level increases, task impairment increases (H. J. Eysenck, 1967; M. W. Eysenck & Calvo, 1992; M. W. Eysenck et al., 2007). However, although high neurotics have a higher arousal level, as the demand increased from a dual task with non-degraded stimuli to a dual task with degraded stimuli, the cost differences between the high and low neurotics did not differ as the difficulty increased via stimuli degradation. This may indicate that the arousal level is specifically caused by demand on the switching, inhibition and updating functions and it may impair these CES functions.

Therefore, I conclude that a worry related increased arousal level, as a manifestation of the detrimental effect of neuroticism, may be associated neither with the storage systems nor other types of task difficulty that are disassociated from the CES demand. It may be mainly associated with demand in the central executive system and bottleneck processing that involves the switching, inhibition and updating functions.

7.5 Neuroimaging findings

Part of the original research aim was to examine functional neuroanatomical correlates of neuroticism during dual task processing. This study has made a considerable contribution to the current literature for two reasons. One is that research about functional neuroanatomical correlates of neuroticism regarding cognitive processing is very limited. Recently, one study has shown lower activation in the fronto-parietal executive control network in high neurotics compared to low neurotics during N-back task processing (Dima et al., 2015). Although the study is informative, it has been criticized with regard to the selection of the participants, i.e. instead of comparing high and low neurotics, the authors compared neurotics and consciousness (see section 1.2.2) (Bianchi & Laurent, 2016). The second reason why the current study makes a valuable contribution is that acquiring this data (i.e. current study) allows for drawing a precise conclusion in terms of which brain areas show specific sensitivity to the detrimental effect of neuroticism that impairs the CES functions during task processing. Taken together, the findings in this research provide new insights into the cognitive mechanism in relation to neuroticism related group differences during cognitive task processing.

The results show that the high neurotics had higher dual task costs and PRP effects and at the same time lower dual task specific activations such as in the lateral (IFG, SFG, MFG) and medial (ACC, medSFG) prefrontal cortices. Previously, I highlighted that these anatomical areas are associated with dual task performance (Sigman & Dehaene, 2005; Stelzel et al., 2008b; Szameitat et al., 2002; Szameitat et al., 2016). More specifically, it has been suggested that activation in these areas is related to the switching, inhibition and updating functions for resolving interference by maintaining and coordinating the processing of the tasks at the stage of a processing bottleneck (Szameitat et al., 2002; Szameitat et al., 2016). For example, IFG is activated to inhibit the first task until the second has been processed (Konishi et al., 1999; Levy & Wagner, 2011; Schubert & Szameitat, 2003; Szameitat et al., 2006; Szameitat et al., 2002; Szameitat et al., 2016). MFG is activated to switch the focus of the bottleneck from one task to another one (Brass et al., 2005; Brass & von Cramon, 2002; Dove et al., 2000; Sohn et al., 2000). ACC activations have been shown during the updating of task sets and contexts and during error execution in task processing (Dosenbach et al., 2006, 2008; Fleck, Daselaar, Dobbins, & Cabeza, 2006; MacDonald, Cohen, Stenger, & Carter, 2000; Rowe, Hughes, Eckstein, & Owen, 2008).

Lower activity in these areas is suggested to indicate less efficient mental processing, which consequently means that behavioural performance suffers (Bishop, 2009; Dima et al., 2015). This interpretation is consistent with my behavioural findings (chapter 3-5). I have shown that high level neuroticism impairs performance in demanding tasks that are strongly associated with the CES functions. However, it does not impair task processing when the demand is increased in other ways such as in the VSSP or in the perceptual stage of a dual task. Therefore, the cause of task impairment seems to be due to demand on the CES functions. Based on this information, decreased activations in the reported areas in high neurotics seem to be associated with impairment in the switching, inhibition and updating functions.

ACT (M. W. Eysenck et al., 2007) agrees with the argument that neuroticism is associated with a broad impairment of the switching, inhibition and updating functions. Originally, ACT suggested evidence of a higher impairment on these CES functions, and that greater activation would be observed in cognitive control regions in high neurotics compared with low neurotics. However, following a study by Bishop, (2009) showing that a worry related increased arousal level may cause lower activations in the cognitive control regions, a recent theoretical paper on ACT (M. W. Eysenck & Derakshan, 2011) has revised the prediction. Accordingly, ACT, suggested that the detrimental effect of neuroticism may lead to decreased activation in the cognitive control regions, if high neurotics cannot invest efficient mental effort into the task (M. W. Eysenck & Derakshan, 2011). Translating this into the current findings, high neurotics were observed to have decreased activations in the dual task specific regions while they had a higher behavioural dual task cost and PRP effect in the dual task performance, which required extensive use of the switching, inhibition and updating functions. The reason for that may be that the worry related increased arousal level causes greater task irrelevant activities that in turn overlap with task related activities and limit the investment of efficient mental effort in the CES functions (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011). This situation seems to impoverish the prefrontal control of attention (Bishop, 2009; Dima et al., 2015) in dual task specific areas.

In line with the above paragraph, DMC theory (Braver, 2012; Burgess & Braver, 2008) suggests that lower activity in these areas indicates less efficient mental processing, so that consequently behavioural performance suffers. In detail, in high neurotics, a worry related increased arousal level causes higher task irrelevant activities (Braver, 2012; Burgess & Braver, 2008; Sarason et al., 1990). In such situations, a reactive control mechanism, which is associated with task irrelevant activities, becomes more dominant (Braver et al., 2007; Braver, 2012; Burgess & Braver, 2008). Because using this mechanism often suppresses the cognitive control regions (Bishop, 2007; Bishop, 2009; Braver, 2012), it causes lower activations in the cognitive control regions by limiting the recruitment of efficient cognitive resources (Bishop, 2009; Braver et al., 2007; Braver, 2012; Burgess & Braver, 2008).

To my knowledge this is the first study to investigate the effect of neuroticism on the functional neuroanatomical correlates of dual task processing. The findings seem to provide sufficient evidence about the effect of neuroticism on the CES functions regarding brain activations in the cognitive control regions. I suggest that lower activations in dual task specific areas are associated with an impairment of the CES functions during dual task processing. This is because decreased dual task specific activations were shown at the same time with higher behavioural costs in high neurotics compared with low neurotics. In support of that, my previous behavioural studies (chapter 1-5) showed a higher behavioural dual task cost and that high level neuroticism impairs only the three CES functions and does not influence the demand on the storage system i.e. VSSP and perceptual stages.

7.6 Conclusion and further directions

The purpose of this thesis was to provide a more accurate description of behavioural and neural correlates of neuroticism related group differences during dual task processing. Through the use of behavioural experiments, the detrimental effect of neuroticism was shown on the CES functions in both standard WM tasks and dual tasks. As evidence that the detrimental effect of neuroticism impairs the switching, inhibition and updating functions, the studies have shown that neuroticism related group differences become larger through increasing the demand either by task order coordination or task set maintenance. However, the neuroticism related group differences were not influenced when the task demand was increased in the storage systems i.e. the VSSP and perceptual stage of dual task processing.

The perceived higher stress and difficulty level in relation to the neuroticism related group differences refers to an increased arousal level, which caused a higher task impairment in the high neurotics, which might be specific to higher CES demand. Finally, through the use of an FMRI study, lower dual task specific activations and at the same time higher dual task costs were observed in the high neurotics compared to the low neurotics. This indicates that decreased activations in dual task specific areas may be associated with an impairment to the switching, inhibition and updating functions. The behavioural and neuroimaging results seem to be sufficient to suggest that high neuroticism impairs the three main CES functions (Derakshan & Eysenck, 2009; M. W. Eysenck et al., 2007; M. W. Eysenck & Derakshan, 2011), which are associated with inefficient recruitment of cognitive resources in dual task specific areas (Bishop, 2009; Dima et al., 2015).

Collectively, behavioural and neural correlates of neuroticism related differences are most likely to contribute to the cognitive impairments revealed due to the detrimental effect of neuroticism during demanding tasks associated with the main functions of the CES. Thus, the results presented here should be considered as a platform for future studies to build upon. The continued investigation in terms of neuroticism related differences during demanding cognitive tasks is fundamental to draw near to a more consolidated conceptualization of cognitive impairments in high neurotics. Hopefully, this will then allow for the development of treatments that can help to alleviate the deficits associated with neuroticism.

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APPENDICES

Appendix A: a screening sheet that includes participant's information and psychiatric and neurologic history of participants

SCREENEND BY: **SCREENING DATE:**

SCREENING QUESTIONNAIRE

Name:	**Occupation:**
Date of Birth:	**Age:**
Sex: M / F	**Handedness: R/ L/ Both:**
School leaving age:	**Further education:**

1. Are fluent in English? Not very well 1—2-- 3—4—5--- 6--- 7 – English is my first language
2. Do you drive? (if yes, please state how many years you have been driving for and how many hour/per week you drive)

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3. Have you ever visited a psychiatrist, psychologist or neurologist? (if yes, please give details)

---

4. Do you have a history of epilepsy or diabetes?
5. Are you currently taking medication? (if yes, then please give details)

---

6. Do you smoke? (if yes, how many cigarettes/ per day)
7. Do you have any sight or hearing problems?
8. Do you have any difficulties with reading or writing such as dyslexia?
9. Are you (do you think you may be) pregnant? Y / N N/A
10. Is there any relevant medical/other information you have not told us about?

    (E.g. completed psychology tests, familiar with computer games)

Appendix B: alcohol and caffeine survey that is used for exclusion criteria

Name:__________________ Date:__________________

Alcohol Survey

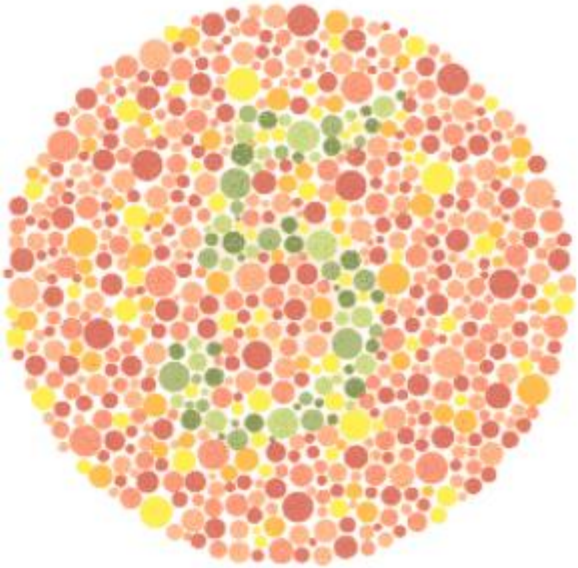
1. Have you ever felt you ought to cut down your drinking? Yes / No
2. Have people annoyed you by criticising your drinking? Yes / No
3. Have you ever felt bad or guilty about your drinking? Yes / No
4. Have you ever hand a drink first thing in the morning to steady your nerves or get rid of hangover? Yes / No

Caffeine Survey

1. How many cups of tea do you drink per day? ☐
2. How many cups of coffee do you drink per day? ☐

   Do you drink decaffeinated coffee? Y / N
3. How many cups of hot chocolate do you drink per day? ☐
4. How many cans of fizzy soft drinks (caffeinated) e.g coke, do you drink per day? ☐
5. How many cans of sports drink e.g. Lucozade do you drink per day? ☐

Appendix C: an example of Ishara colour blind test that is used for exclusion criteria



Appendix D: Neuroticism scale of EPQ which is used for recruitment of high and low neurotics.

INSTRUCTIONS: Please answer each question by putting a circle around the "YES" or "NO" following the questions. There are no right or wrong answers, and no trick questions. Work quickly and do not think too long about the exact meaning of the questions.

PLEASE REMEMBER TO ANSWER EACH QUESTION

1. Does your mood often go up and down? **YES / NO**
2. Do you ever feel 'just miserable' for no reason? **YES / NO**
3. Do you often worry about things you should not have done or said? **YES / NO**
4. Are you an irritable person? **YES / NO**
5. Are your feelings easily hurt? **YES / NO**
6. Do you often feel 'fed up'? **YES / NO**
7. Are you often troubled about feelings of guilt? **YES / NO**
8. Would you call yourself a nervous person? **YES / NO**
9. Are you a worrier? **YES / NO**
10. Do you worry about awful things that might happen? **YES / NO**
11. Would you call yourself tense or 'highly strung'? **YES / NO**
12. Do you worry about your health? **YES / NO**
13. Do you suffer from sleeplessness? **YES / NO**
14. Have you often felt listless and tired for no reason? **YES / NO**
15. Do you often feel life is dull? **YES / NO**
16. Do you worry a lot about your looks? **YES / NO**
17. Have you ever wished that you were dead? **YES / NO**
18. Do you worry too long after an embarrassing experience? **YES / NO**
19. Do you suffer from nerves? **YES / NO**
20. Do you often feel lonely? **YES / NO**
21. Are you easily hurt when people find a fault with you or the work you do? **YES / NO**
22. Are you sometimes bubbling over with energy and sometimes very sluggish? **YES / NO**
23. Are you touchy about some things? **YES / NO**
24. When your temper rises, do you find it difficult to control? **YES / NO**

Appendix E: An example of consent form which is used in the cantab and dual task experiments.

CONSENT FORM

Neuroticism Related Differences on Cognitive Processing of Dual Task in Healthy Volunteers

The participant should complete the whole of this sheet		
	Please tick the appropriate box	
	YES	NO
Have you read the Research Participant Information Sheet?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Have you received satisfactory answers to all your questions?	☐	☐
Do you understand that you will not be referred to by name in any report concerning the study?	☐	☐
Do you understand that you are free to withdraw from the study:		
• at any time?	☐	☐
• without having to give a reason for withdrawing?	☐	☐
Do you agree to take part in this study?	☐	☐
Signature of Research Participant:		
Date:		
Name in capitals:		

Researcher name: Rahmi Saylik	Signature:
Supervisor name: André Szameitat	Signature:

Appendix F: An example of debriefing form for dual tasks that is given to participants after completion of the experiments.

DEBRIEFING FORM:

The effects of neuroticism on dual task cognitive processing in healthy volunteers

There are a number of findings related to why neurotics may have cognitive impairments. For example, stress and working memory load may cause slower processing of cognitive tasks (Eysenck, Derakshan, Santos, and Calvo, 2007). This interference may be caused by limited resources of WM system (Eysenck, Derakshan, Santos, and Calvo, 2007). However, no studies to date have assessed effect of working memory load on cognitive processing in the context of psychological refractory period (PRP) dual-task paradigm in highly neurotic never depressed group. The present study is aimed to explore Neuroticism-related differences in the PRP-paradigm.

Dual task is defined as performing two tasks concurrently. Dual-task can take place when someone tries to perform two tasks simultaneously, switch from one task to another, or perform two or more tasks in rapid succession.

The Eysenck Personality questionnaire (EPQ) is a questionnaire used to assess personality traits. It is measured along three dimensions: Extraversion/Introversion, Neuroticism/Stability, and Psychoticism/Socialization.

The hypothesis to be tested is that individuals with high scores on the neuroticism scale of the Eysenck Personality Questionnaire (EPQ) will have higher dual task cost compared to individuals with lower scores on neuroticism when working memory load increases in dual task PRP paradigm.

The following studies, on the above topic, might be of interest to you:

Matthews, G., & Davies, D. R. (2001). Individual differences in energetic arousal and sustained attention: A dual-task study. *Personality and Individual Differences, 31*(4), 575-589.

Studer-Luethi, B., Jaeggi, S. M., Buschkuehl, M., & Perrig, W. J. (2012). Influence of neuroticism and conscientiousness on working memory training outcome. *Personality and Individual Differences, 53*(1), 44-49

We would like to thank you again for your participation in this study. Please feel free to contact Rahmi SAYLIK hspgrrs@brunel.ac.uk via email.