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Neurocognitive Processes Underpinning Different Aspects of Mental Robustness in British Military Personnel

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Neurocognitive Processes Underpinning Different Aspects of Mental Robustness in British Military Personnel

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Contents

Tables & Figures

Chapter 1 - General Introduction

Chapter 2 - Developing a Reliable and Valid Measurement Instrument

Chapter 3 - Measuring mental robustness on military operations (MR-MO) with UK Armed Forces

Chapter 4 - Functional magnetic resonance imaging (fMRI)

Chapter 5 - Neurocognitive processes underpinning different aspects of mental robustness in UK Armed Forces

Abbreviations

ADF	Asymptotically Distribution Free
BAS	Behavioural Approach System
BIC	Bayesian Information Criterion
BIS	Behavioural Inhibition System
BOLD	Blood Oxygenation Level Dependent
BSEM	Bayesian Structural Equation Modelling
BPS	British Psychological Society
BRS	Brief Resilience Scale
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CSF	Cranial Spinal Fluid
dACC	Dorsal Anterior Cingulate Cortex
DCC	Dismounted Close Combat
df	Degrees-of-freedom
DIC	Deviance Information Criterion
DoD	Department of Defence
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, 4th Edition
Dstl	Defence Science and Technological Laboratory
EBA	Extrastriate Body Area
EFA	Exploratory Factor Analysis
EPI	Echo-Planer Imaging
EPQ-RS	Eysenk Personality Questionnaire – Revised Short Edition
ESEM	Exploratory Structural Equation Model
FFA	Fusiform Face Area

FFFS	Fight-Flight-Freeze System
fMRI	Functional Magnetic Resonance Imaging
GCSE	General Certificate of Secondary Education
GLM	General Linear Model
HADS	Hospital Anxiety and Depression Scale
HRF	Hemodynamic Response Function
ICM	Independent Clusters Model
IF	Incidental Findings
INF	Infantry Personnel
ISC	Inter-Subject Correlation
K-S	Kolmogorov-Smirnov
LRT	Likelihood Ratio Test
MCMC	Markov Chain Monte Carlo
ML	Maximum Likelihood
MNI	Montreal Neurological Institute
MoD	Ministry of Defence
MoDREC	Ministry of Defence Research Ethics Committee
MR	Mental Robustness
MRec	Mental Robustness for emotional challenges
MRI	Magnetic Resonance Imaging
MR-MO	Measure of Mental Robustness for Military Operations
MRp	Mental Robustness for pressured performance
MTI	Military Toughness Inventory
MTMTI	Military Training Mental Toughness Inventory
MTQ	Mental Toughness Questionnaire

n	Symbol used for the number of subjects
NATO	North Atlantic Treaty Organisation
NCO	Non-Commissioned Officer
NMR	Nuclear Magnetic Resonance
NNFI	Non-Normed Fit Index
OR-3	Lance Corporal
OR-8	Warrant Officer Class 2
PARA	Parachute Regiment
PCA	Principle Components Analysis
PCL	PTSD Checklist
PCL-M	PTSD Checklist – Military Edition
PFC	Prefrontal Cortex
PPA	Parahippocampal Place Area
PPC	Posterior Predictive Checking
PPP	Posterior Predictive *p*
PS	Punishment Sensitivity
PSR	Potential Scale Reduction
PST	Physical Skills Training
PTE	Potentially Traumatic Event
PTSD	Post-Traumatic Stress Disorder
PTSS	Post-Traumatic Stress Symptoms
RF	Radiofrequency
RM	Royal Marine Commando
RMSEA	Root Mean Square Error of Approximation
ROI	Region of Interest

RS	Reward Sensitivity
RS-fMRI	Resting State Functional Magnetic Resonance Imaging
RST	Resting State Theory
rRST	Revised Resting State Theory
SEM	Structural Equation Model
SF	Special Forces
SMTQ	Sport Mental Toughness Questionnaire
SRMR	Standardized Root Mean Square Residual
T	Tesla
TBI	Traumatic Brain Injury
TLI	Tucker-Lewis Index
TR	Repetition Times
UK AF	United Kingdom Armed Forces
UOTC	University Officer Training Corps
VBS	Virtual Battle Space
vmPFC	Ventral Medial Prefrontal Cortex
WIA	Wounded in Action
χ^2	Chi-Squared

Abstract

Military personnel are required to perform effectively in extreme enviroments. Optimal performance in combat enviroments is a complex process and its neural basis is poorly understood. Understanding the factors that influence how an individual is able to perform to a high standard *and* cope with the demands of the situation while under extreme operational stress is vital. As stressful events can have a lasting impact on soldiers and while for some deployment can lead to positive change for others it can increase the risk of suffering from post-traumatic stress disorder (PTSD). To better understand how soldiers are able to perform effectively, in the first study of the thesis we developed a psychometrically robust measure of mental robustness that was informant rated and relevant to combat operations. The measure assesses a soldier's ability to make decisions under pressure and their ability to function effectively when faced with emotional challenging situations as two separate dimensions. A second study confirmed the factor structure of the measure and also provided initial evidence for its construct validity. The measure underpinned our final study (Study 3) which combined psychometric measures, behavioural and functional imaging to produce a deeper understanding of the relationship between activity in key brain regions and key components of robustness. Study 3 assessed soldier's ability to make decisions under pressure when presented with combat relevant stimulus. The study employed two tasks; Task 1 required individuals to attend to emotional aspects of the stimuli as they would do in during combat and Task 2 required soldiers to attend to the non-emotional aspects of the stimuli. Our findings suggest that robustness acts as a resistance resource and although it does not protect against PTSS it does allow a curvilinear relationship between PTSS and performance. The ultimate goal of this thesis is to better understand the critical factors required for optimal military performance during deployment. This will allow more targeted training that will help highly motivated individuals achieve excellence.

Chapter 1

General Introduction

1.1 Understanding robustness as a dimension of mental toughness

Mental toughness has caught the attention of both the academic community and the general public for a number of decades and has been studied as an important individual difference factor (Lin, Mutz, Clough & Papageorgiou, 2017). Mental toughness was initially conceptualised as an inherited innate personality characteristic (Werner, 1960; Werner & Gottheil, 1966; Kroll, 1967). However more recent research (e.g. Bull, Shamrock, James & Brooks, 2005; Thelwell, Weston & Greenlees, 2005) suggests that mental toughness can be learned. This apparent dichotomy to understand mental toughness has resulted in much confusion in the field and has lead to the legitimacy of mental toughness as a scientific construct being questioned (Anderson, 2011; Caddick & Ryall, 2012).

As an informal term to describe people (particularly athletes) mental toughness is widely used in a wide variety of ways. However, as a formal construct, it is defined in a number of different ways with little conceptual clarity (Crust, 2007). For example, on one view *"Mental toughness is the ability to achieve personal goals in the face of pressure from a wide range of different stressors"* (Hardy, Bell & Beattie, 2013, p. 70), and on another mental toughness is the *"…unshakable perseverance and conviction towards some goals despite pressure or diversity"* (Middleton, Martin & Marsh, 2011, p. 94). Other definitions include: an ability to cope with or handle pressure, stress, and adversity (Goldberg, 1998; Gould, Hodge, Peterson, & Petlichkoff, 1987; Williams, 1988); an ability to overcome or rebound from failures (Dennis, 1981; Taylor, 1989; Tutko & Richards, 1976; Woods, Hocton, & Desmond, 1995); an ability to persist or a refusal to quit (Dennis, 1981; Goldberg, 1998; Gould et al., 1987); coping effectively with pressure and adversity so that performance remains little affected (Clough, Earle & Sewell, 2002; Jones, 2002; Loehr, 1995; Middleton, Marsh, Martin, Richards & Perry, 2004; Williams, 1988); an insensitivity or resilience (Alderman, 1974; Goldberg, 1998; Tutko & Richards, 1976); and the possession of superior mental skills (Bull et al., 1996; Loehr, 1982, 1995). Most recently, Daniel Gucciardi (2017, p. 5) defined mental toughness as *"a state-like psychological resource that is purposeful, flexible, and efficient in nature for the enactment and maintenance of goal-directed pursuits"*.

Gucciardi (2017) goes on to conceptualise mental toughness as a *"resource caravan"* (p. 6) where dimensions accumulate and integrate over time. This suggests that mental toughness represents a one-dimensional concept where psychological resources evolve enabling individuals to foster goal-directed behaviour (Gucciardi, Hanton & Fleming, 2017). However, other research relating to the conceptualisation of mental toughness has presented it as a multidimensional model. Clough et al., (2002) argued that mental toughness resembled tenets outlined in hardiness theory in which four interrelated dimensions (commitment, control, challenge and confidence; the 4Cs) provide an individual with existential courage and motivation to assess stressful situations as opportunities for growth (cf. Maddi 2004, 2006). Gucciardi (2017) however argues that there has been little justification for the distinctiveness of the 4Cs model. He questions what the necessary and sufficient attributes of mental toughness are for the inclusion of these four dimensions but not the inclusions of other dimensions such as 'flexibility' (Gucciardi, 2017).

Clearly, mental toughness is open to diverse interpretations. As such it has been argued that this lack of consensus is related to idiosyncratic differences in interpretation (Fawcett, 2011). Put simply, people explain mental toughness based on their own experience (depending on age, gender, and culture) and situational circumstances (e.g., sports performance, recovering from injury, suffering bereavement). The lack of a clear conceptualisation and operational definition of mental toughness has for some time resulted in limited attempts to develop inventories that profile and assess mental toughness.

1.1.1 Measure of mental toughness

Over the years a number of measures (almost as many as there are definitions) have been developed to assess, quantify and operationalise mental toughness particularly within the field of sport. These include the Mental Toughness Questionnaire-48 (MTQ48), which is widely used as a general sports measure of mental toughness (Crust & Azadi, 2009; Crust, 2009; Nicholls, Polman, Levy & Backhouse, 2008). Recognising that mental toughness is arguably interpreted differently within different situational circumstances (e.g. sports performance, military training) a number of context-specific measures of mental toughness have been developed. These have been developed for specific sports, such as the Cricket Mental Toughness Inventory (CMTI; Gucciardi & Gordan, 2009) and the Australian Football Mental Toughness Inventory (AfMTI; Gucciardi, Gordon & Dimmock, 2009) as well as for different environments, such as military training.

The Military Training Mental Toughness Inventory (MTMTI; Arthur, Fitzwater, Hardy, Beattie & Bell, 2015) is one such example. The MTMTI is an informant-rated measure that specifically examines a soldier's ability to perform under pressure within a military training environment. Arthur's (2015) findings using this measure suggest that mental toughness is an important resource for the fulfilment of one's potential. It has been reported that self-actualisation (also known as the fulfilment of one's potential) is a key conceptual thread between mental health and mental toughness (Gucciardi, et al., 2017). Performance failures have been reported to elevate risk of mental ill health with mental toughness acting as a resistance resource as it fosters high performance (Gucciardi, et al., 2017). Within this thesis, we first look to develop a measure that is relevant to combat operational environments. Unlike the MTMTI, which only measured a soldier's ability to continue to perform in complex environment this measure will also look to examine the impact of emotional challenges on performance as a separate dimension.

1.1.2 Mental toughness moving forward

In a bid to simplify and disentangle mental toughness as a construct we propose, like Gucciardi (2008, 2015, 2017), that it should be used as an umbrella term. By this, mental toughness within this thesis is used to refer to the recipe of psychological components (e.g. flexibility, confidence, control) that appear to set apart good and great performance in individuals (Gucciardi, et al., 2008). In addition to proposing that mental toughness is considered an umbrella term we further propose that mental toughness research should be approached from a mental robustness perspective (in which researchers examine components of mental toughness in relation to an individuals ability to continue to perform in the face of adversity) or from either a mental resilience perspective (in which researchers examine components of mental toughness in relation to an individuals ability to bounce back from adversity).

Mental Resilience. The use of the term 'mental resilience' also muddies the waters as it is often used interchangeably with mental toughness as they share a common thread (Gucciardi, 2017). Research investigating mental resilience has to some extent been a little clearer with measures developed to exclusively assess this dimension (e.g. Connor-Davidson Resilience Scale (CD-RISC), Connor & Davidson, 2003; Resilience Scale for Adults (RSA), Friborg, Barlaug, Martinussen, Rosenvinge & Hiemdal, 2005; Brief Resilience Scale (BRS), Smith, et al., 2008). However, reviews of current measures still draw into question the extent to which researchers are actually measuring resilience (Windle, Bennett & Noyes, 2011). For example, the BRS (Smith et al., 2008) is an eight-item measure yet only six of the items are actually measuring resilience.

Establishing mental robustness and mental resilience as separate topics of investigation under the umbrella of mental toughness may help untangle the construct as they have divergent effects on particular outcomes. For example, resilience might have more positive links to mental health under times of stress than robustness, but robustness might predict performance under pressure better. Having said this, resilience might predict a soldier's ability to perform better in an upcoming operation if they have performed poorly previously whereas robustness might not predict this so well. Considering this, within this thesis we will only use the term 'mental toughness' as an umbrella term to describe general performance. The term 'mental robustness' will be used when referring specifically to one's ability to continue to perform in the face of adversity and 'mental resilience' refers to one's ability to bounce back from adversity.

1.2. Mental Robustness and the Military

A career in the military regularly challenges service members. The nature of such a vocation results in exposure to potentially traumatic events (PTE) for many, whether that is during combat, peace support, or humanitarian operations. However, wartime traumatic experiences are distinct from other traumatic events, such as natural disasters, terminal illness, or traffic accidents (Linley & Joseph, 2004). Those in the United Kingdom Armed Forces (UK AF) voluntarily put themselves at risk of experiencing PTEs and are also required to simultaneously perpetrate PTE on the enemy. This type of trauma is unique to those serving in the military (Larner & Blow, 2011).

The asymmetric nature of recent conflicts in Iraq and Afghanistan saw personnel frequently exposed to traumatic events, particularly those deployed in ground close combat roles (Cabrera et al., 2007; Macmanus, et al., 2014; Osório, et al., 2017; Rona et al., 2009;

Smith, et al., 2008). Repeated exposure to traumatic events has been linked to negative health outcomes such as post-traumatic stress disorder[1] (PTSD). The severity of PTSD symptoms is often proportional to the intensity and duration of traumatic experiences such as those encountered in Iraq and Afghanistan (Fear, et al., 2010; Hoge, et al., 2004; Osório, et al., 2013). For soldiers serving in the UK AF, deployments in Afghanistan during 2009 and 2010 were some of the deadliest with nearly as many personnel killed in this two-year period as in the other eight years combined.

The vast majority of service personnel who are exposed to traumatic events will not experience undue distress or develop any formal psychiatric illness. However, a small proportion of individuals will suffer from sufficient subsyndromal symptoms that will reduce their operational efficiency (Greenberg, Langston, & Jones, 2008). Response to combat trauma varies not only from soldier to soldier but also between military occupational groups (Sundin, et al., 2010). Given the multiple and varied stressors that soldiers face on a daily basis (in training and on operations), military settings provide a unique opportunity to study *mental robustness* – the ability to continue to perform under pressure even in the face of adversity. Despite this, there is still very little empirical research regarding this phenomenon, instead research has largely focused on the negative mental health consequences of military service (e.g., Fear, et al., 2010; Osório, et al., 2013, 2017; Rona, et al., 2009).

1.2.2 Performance under pressure.

During the past decade, additional efforts have been made to further our understanding of performance outcomes in the military. The research has investigated

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[1] PTSD is an anxiety disorder that may develop after experiencing an event that involved actual or threatened death or serious injury to themselves or others and resulted in feelings of intense fear, helplessness, or horror (Frappell-Cooke, Gulina, Green, Hacker Hughes, & Greenberg, 2010).

military populations in the context of basic training and selection (e.g. Arthur, et, al., 2015; Arthur, et al., 2017; Fitzwater, Arthur & Hardy, 2017), or in the context of operational deployments (e.g. Fear, et al., 2010; Hoge, et al., 2004; Killgore, et al., 2008; Osório, et al., 2013, 2017).

Training and selection.

Isolating the variables that bear on individual mental robustness is difficult. However, a number of factors (e.g., preparedness, team cohesion, comradeship) have been identified to explain why a group of soldiers can return home from operational deployment with essentially the same experiences, yet some will experience negative psychological health outcomes (Larner & Blow, 2011) while others may experience increased self-efficacy after mastering a stressful deployment (Frappell-Cooke, et al., 2010).

The UK AF elite units (Special Forces (SF), Parachute Regiment (PARAs) and the Royal Marine Commandos (RMs)) carry out the most extremely demanding operational tasks. Deploying more frequently and on more hazardous duties in newly established theatres puts soldiers from these units at increased risk of experiencing PTEs. Training for these elite units is widely regarded as the most physically and mentally demanding in the UK AF; transforming recruits' beliefs, attitudes, values and standards as well as improving their physical fitness (Hardy, et al., 2010). At present, there is very little research (see Arthur, et al., 2015; Fitzwater, et al., 2017; Simpson, Gray & Florida-James, 2006 for exceptions) that specifically addresses mental robustness in a military training environment[2]. Simpson et al.,

[2] Various terms have been used to describe the ability to perform under pressure and the precise terminology used has received considerable and intense scrutiny with different authors using different terms for similar constructs (Bull et al., 1996; Clough, Earle & Sewell, 2002; Dennis, 1981). The purpose of this work is not to critique these different terms. The research that has been conducted with military populations focused on what they called

(2006) conducted a simple group comparison between PARA reservists and SF reservists during a training exercise and found no significant difference in self-reported mental robustness between these units. The lack of significant findings by Simpson, et al., (2006) is likely to be related to socially desirable responding as a result of employing a self-report measure of robustness. However, the training environment may have also played a part.

Research by Fitzwater, et al., (2017) examined the impact of a psychological skills training (PST) intervention on observer-rated mental robustness from 222 PARA recruits. The PST targeted goal setting, relaxation and arousal regulation, self-talk strategies and imagery/mental rehearsal. Results revealed that individual performance was significantly higher in the experimental group than the control group. However, although no significant difference between the control and experimental group on mental robustness they did find an interaction effect. Those who had received PST scored significantly higher in mental robustness post-training than pre-training while those who had not received PST saw no improvement. These findings indicate that PST has a positive impact on observed mental robustness.

To understand the relationship between mental robustness and military training, researchers may be better comparing elite units with regular service personnel who also serve in ground close combat roles (e.g. Army Infantry Regiments). Research comparing regular forces and elite units (Sundin, et al., 2010; Hanwella & de Silva, 2011; Larson, Highfill-McRoy, & Booth-Kewley, 2008) has previously shown a difference between elite and regular units. However, these studies only provided indirect evidence of mental robustness inferred via an absence of PTSD symptoms. One of the most notable aspects of basic and peacetime

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mental toughness but here their research is referred to as addressing mental robustness as their research is specifically about continuing to perform well under pressure.

training is the absence of some of the key stresses (e.g., risk to life) associated with actual combat conditions. Research by Larson et al., (2008) found significant group differences in rates of PTSD between deployed and non-deployed US Marines. Considering this, if we want to understand the role of robustness in the military we need to understand it in the context of operational deployment.

Operational deployment.

The ability to perform under extreme pressure is a quality sought by all, whether in the military, the police, emergency medicine or sport. Combat environments see soldiers faced with unprecedented challenges regarding: information management, decision making, adaptive motor responses, the control of fear and fear-related thoughts as well as the control of reckless behavior; all of which are critical both to mission success and survival (Carston & Gardner, 2009; Driskell, Salas & Johnston, 2006; Pori, Tušak & Pori, 2010; Ward, et al., 2015). Attentional lapses, narrowing of perceptual focus and/or biased information processing can contribute to errors in judgement and performance (Orasanu & Backer, 1996).

A soldier's ability to continue to perform when presented with a life or death situation is not well understood due to the inherent difficulties associated with data collection in combat environments. As such, there is no empirical research that has examined robustness in relation to operational deployment. Instead, research with military personnel has focused on training contexts often with personnel who have no combat experience (Arthur, et al., 2015; Fitzwater, et al., 2017).

Situations involving the need to assess threats can frequently occur in the presence of heightened emotional states. Operational environments present a wide variety of emotional challenges, these can include but are not exclusive to: witnessing trauma, exposure to death or injury (either as a subject or as an agent), and more peripheral experiences (e.g. handling human remains) (Guyker, et al., 2013; Kimbrel, et al., 2014; Sudom, Watkins, Born &

Zamorski, 2016). Many posit that emotions evolved to provide pertinent information about one's immediate surroundings and to help people take appropriate action (Barrett, Mesquita, Ochsner, & Gross, 2007; Baumann & DeSteno, 2010; Clore, Gasper, & Garvin, 2001; Ellsworth & Scherer, 2003; Schwarz & Clore, 2007). The elicitation of intense emotional responses and uncontrolled arousal due to emotional challenges in combat conditions can consume, undermine and degrade a soldier's ability to execute their responsibilities (Thompson & McCreary, 2006).

Research examining the emotional challenges of operational deployment has focused on the psychological cost of experiencing such challenges (Fear, et al., 2010; Hanwella & de Silva, 2012; Hoge, et al., 2004; Killgore, et al., 2008; Osório, 2013, 2017); rather than looking to understand how the vast majority of soldiers (Fear, et al., 2010) continue to perform and do not break down when faced which such horrific circumstances. A number of studies examining the negative health consequences of operational deployment have inferred that an absence of pathology following traumatic exposure is indicative of robustness (Castro & McGurk, 2007; Larson, Hillfill-McRoy & Booth-Kewley, 2008; Smith, et al., 2009; Sundin, et al., 2010). Research by Sundin et al. (2010) compared occupational risk factors and differences in mental health outcomes in two UK AF elite units (PARA and RMs) and Army infantry personnel (INF). They reported lower levels of PTSD symptoms in RMs post-deployment and higher levels of unit cohesion compared to PARAs and INF (Sundin et al., 2010). The results also indicated that PARAs were less stress-reactive to witnessing trauma to others than both the INF and RMCs (Sundin et al., 2010). Sundin and colleagues cited unit cohesion and preparedness as possible protective factors against PTSD symptoms post-deployment, with elite units being more robust than regular troops. In a similar study, basic training for elite units was identified as acting as a de facto psychological screening process wherein recruits must be robust to succeed and therefore symptoms of PTSD in these units will be lower (Larson, et al., 2008).

Measuring robustness via the absence of PTSD fails to cover the multi-dimensional, nature of mental robustness (van der Werff, Van Den Berg, Pannekoek, Elzinga & Van Der Wee, 2013). To date, there is no research specifically examining how personnel are able to continue to perform when faced with emotional challenges (hence forth “MRec”) associated with deployment. In fact, much of the mental robustness research has largely focused on decision making under pressure (hence forth “MRp”; e.g., Arthur, et al., 2015; Fitzwater, et al., 2017) which in the context of the military does not capture the emotional challenges of combat. With this in mind the first overarching aim of the PhD research was to develop an informant rated measure of mental robustness that was operationally relevant and also focused on two components of mental robustness – MRp and MRec.

1.3. Understanding Mental Robustness from a Neurocognitive Perspective

When individuals are acutely exposed to a number of stressors, cognitive performance is substantially degraded (Liberman, Tharion, Shukitt-Hale, Speckman & Tulley, 2002). There are numerous anecdotal documentations of the devastating impact of combat on the ability of soldiers to process cognitive information and act quickly, effectively, and decisively during the “*fog of war*” (Clausewitz, 1993; Kiesling, 2001; McNamara, 2004). Optimal performance in extreme environments is a complex process and its neural basis is poorly understood. There is a surging interest in the use of neuroscience approaches to examine and possibly improve performance in military personnel (e.g. Ćosić, et al., 2012; Paulus, et al., 2009, 2010; Simmons, et al., 2012). Insight into soldiers' neurocognitive processes during combat operations would provide insight into how some personnel are able to attenuate their emotional response to such extreme environments allowing them to stay “cool under pressure”.

1.3.1 Cognitive impairments. The destruction of war doesn't stop when it is over. Experiences during deployment can also have a lasting impact on cognitive functioning in personnel (Disner, et al., 2017). Indeed, individuals diagnosed with PTSD are known to suffer from impaired cognitive functioning associated with an inability to extinguish fear (Blechert et al., 2007; Peri et al., 2000) and attentional and memory biases to threat-relevant information (Constans, McCloskey, Vasterling, Brailey, & Mathews, 2004; McNally, Kaspi, Riemann, & Zeitlin, 1990; McNally, Lasko, Macklin, & Pitman, 1995). This is particularly true when presented with fear-related stimuli (King, King, Guandanowski, & Vreven, 1995; King, King, Vogt, Knight & Samper, 2006). However, research examining the relationship between pre-deployment neurocognitive performance (measured by learning and memory processes) and PTSD in US Army personnel found that pre-deployment neurocognitive performance acts as a buffer against the adverse effects of operational deployment (Marx, Doron-Lamarca, Proctor & Vasterling, 2009). These findings highlight the potential role of pre-trauma neurocognitive functioning in moderating the effects of trauma exposure on PTSD symptoms.

It is important to note that exposure to trauma influences cognitive functioning regardless of whether the individual is suffering from PTSD or not (see Rauch, et al., 2000). Therefore, comparing PTSD sufferers to non-trauma-exposed individuals (e.g. Protopopescu, et al., 2005) may result in a misattribution of group differences to PTSD pathophysiology. Considering this, an individual difference approach rather than group comparisons may better serve researchers aiming to further our understanding of the neurocognitive underpinnings of mental robustness in military personnel which are currently unknown.

1.3.2 Behavioural neuropsychology and robustness.

In a bid to further our understanding of robustness and understand how we might predict it some researchers have examined the neuropsychological underpinnings of mental robustness using ‘Reinforcement Sensitivity Theory (RST; Gray, 1982). Reinforcement sensitivity is understood as the sensitivity toward rewards (or stimuli that imply the likelihood of a reward occurring; Reward Sensitivity or RS) and punishments (or stimuli that implies the threat of punishment; Punishment Sensitivity or PS). RS and PS mediate approach and avoidance behaviour depending on affective states as well as anxiety and impulsivity related personality dimensions (Leue & Beauducel, 2008). The theory predicts that responses to punishments and rewards may vary among individuals depending on the sensitivity of their neuro systems.

RST has had a major influence on motivation, emotion and psychopathology research (Leue & Beauducel, 2008). The original theory comprised two neuropsychological systems controlling behavioural activity relating to inhibition and activation. Gray and McNaughton substantially revised the theory in 2000, resulting in the widely accepted revised RST (rRST). The revision proposed that punishing stimuli should be subdivided as either eliciting anxiety or eliciting fear. This revised approach takes into account that one can avoid threats while still having a reasonable chance of accomplishing the task. This refinement meant that in the rRST, PS is underpinned by the fight-flight-freeze system (FFFS) and the behavioural inhibition system (BIS). The FFFS mediates fear and is activated by threatening stimuli that need not be faced but can simply be avoided. The BIS mediates anxiety and is activated by goal conflicts of all kinds, paradigmatically between approach and avoidance, especially threatening stimuli that must be faced. These two systems are proposed to work in partnership and are activated by aversive stimuli (Corr, 2004). In contrast, RS is underpinned by the behavioural approach system (BAS) which is activated by appetitive stimuli and mediates the emotion of anticipatory pleasure (Gray & McNaughton, 2000).

Threat detection. To safely navigate an operational environment and survive, military personnel must rapidly select sensory information that is relevant to their mission goals, redirecting their attention and changing their course of action when faced with novel and potentially threatening or rewarding stimuli. Research with military cadets found that PS is a highly significant predictor of poor performance during training with fear and anxiety each making a unique and significant negative contribution (Perkins, Kemp, & Corr, 2007). In contrast, research by Hardy, et al., (2013) with elite athletes found that the combination of high punishment sensitivity combined with low reward sensitivity was associated with mental robustness[3]. Hardy and colleagues suggested that this interaction effect may be because robust individuals are predisposed to identify threats quicker than their counterparts. These findings were supported by a replication study that also offered evidence that high PS performers had a more effective "early warning threat detection system" that could be used to maintain or modify goal-directed behaviour (Fenz, 1973).

The contrast in Perkins' (2007) and Hardy's findings may be related to the level of expertise (Hardy, et al., 2013). Research by Perkins and colleagues (2007) tested Army cadets from the University Officer Training Core (UOTC) with less than a year's experience, whereas, Hardy et al. (2013) tested experienced high-level athletes who have had many more years to learn mechanisms enabling them to master stress when under pressure (see also Fenz, 1973). In the context of the military, early threat detection is undoubtedly a significant advantage, providing it is not accompanied by an increase in false positive errors. Research with experienced or elite military personnel would provide a better understanding of the complex relationship between rRST and mental robustness particularly in relation to the early warning system.

1.3.3 Brain regions of interest.

[3] When discussing the research conducted by Hardy, et al., 2013 we refer to their research as addressing mental robustness as their research was about continuing to perform well under pressure.

Over the past decade, fMRI has allowed the study of key structures within the brain involved in the psychobiological mechanisms that may underlie mental robustness (see *Figure 1.1*). In particular, robustness has been associated with the amygdala and ventromedial prefrontal cortex (vmPFC) and increased activation in the hippocampus and insular cortex. These regions of interest are briefly discussed below.

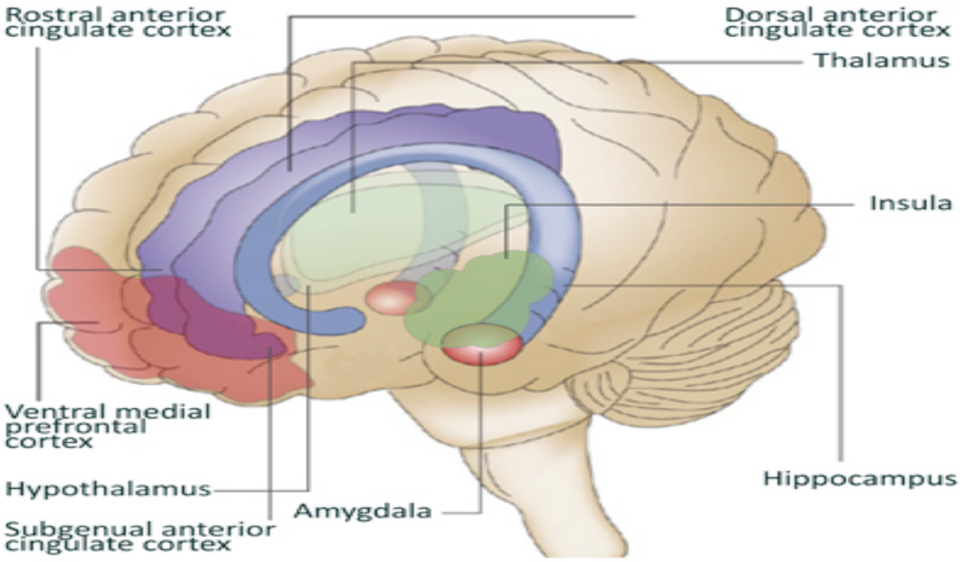

Figure 1.1. - Depicted in this figure are brain regions often involved in robustness to stress. Adapted from Schloesser, Huang, Klein & Manji, (2007).

Amygdala. Emotionally significant experiences tend to be well remembered (McGaugh, 2013). The ability to regulate emotional responses is an important part of normal social behaviour and the amygdala plays a pivotal role in this process (see Roozendaal, et al., 2009). The amygdala is central in emotional learning and memory and is involved in the assessment of threat-related stimuli. When exposed to threat related stimulus neural activity in the amygdala increases. As such, it is essential to the orchestration of arousal-related processes throughout the brain and body mediating the fight-flight response to threat (Davis & Whalen, 2001; Morris, Ohman & Dolan, 1998; Seeley, et al., 2007; Whalen, et al., 1998).

Research has shown that damage to the amygdala results in diminished response to threats (Blanchard & Blanchard, 1972; Pitkänen, Tuunanen, Kälviäinen, Partanen, & Salmenperä, 1998). However, while it is responsible for the detecting and responding to threats it only contributes to feelings of fear indirectly (LeDoux &Pine, 2016).

fMRI based research with military veterans diagnosed with PTSD has shown exaggerated amygdala responses to general threat-related stimuli, with results suggesting that the amygdala plays a fundamental role in the pathophysiology of PTSD (Rauch, et al., 2000). This hyperactivity has been reported during the presentation of personalised traumatic narratives (Rauch, et al., 1996; Shin, et al., 2005), traumatic cues (Driessen, et al., 2004), combat sounds (Liberzon, et al., 1999; Pissiota, et al.,2002), combat photographs (Hendler, et al., 2003; Shin, et al.,1997), and trauma-related words (Protopoescu, et al., 2005). A twin study[4] by True, et al. (1993) with Vietnam veterans suggests that there are significant genetic influences on symptom liability. Even after adjusting for differences in combat exposure, over activation in the amygdala is likely to be a result of both stress exposure and stress vulnerability. More recent research investigating the neural consequences of severe stress exposure (with soldiers both before and after operational deployment) found the stress of combat increases amygdala and insula cortex reactivity (van Wignen, et al., 2011). Given that individuals with PTSD are hypervigilant concerning potential threats in the environment heightened amygdala and insula cortex reactivity is thought to increase the risk of developing mood and anxiety disorders, including PTSD (Stein, et al., 2007; Wolfensberger, et al., 2008).

Hippocampus. The hippocampus is a key component of the limbic system and is involved in explicit memory processes (Corcoran & Maren, 2001; Eichenbaum, 2000).

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[4] *Twin studies* are a type of epidemiological studies designed to measure the contribution of genetics as opposed to the environment, to a given trait (Sahu & Prasuna, 2016).

Research has shown that the hippocampus is critical for episodic memory (Squire & Zola-Morgan, 1991). Damage to the left and right hippocampus leads to impairment in verbal and non-verbal memory function, respectively (Frisk & Milner, 1990; Smith & Milner, 1981).

The hippocampus is also involved in the encoding of context during fear conditioning, interacting with the amygdala during the encoding of emotional memories (Dolcos, LaBar & Cabeza, 2004; McGaugh, 2004). In everyday human experience we learn about the emotional significance of stimuli in the enviroment through experience (e.g., being bitten by a neighbours dog may result in a fear response when you next encounter the dog) or through other means such as verbal communication (e.g., if you hear a neighbour is bitten by their dog you may experience a fear response when you next encounter it). The latter, learning through instruction, requires the hippocampus for acquisition and, possibly for retrieval when the fearful stimulus is presented (Phelps, 2004). Research employing a classic fear-conditioning paradigm, during which a neutral blue square is paired with an aversive shock to the wrist (although no shocks were actually presented), found that patients with amygdala damage fail to show a normal physiological fear response to the blue square, even though they were able to report that the blue square predicted the shock (LaBar, LeDoux, Spencer & Phelps, 1995). In contrast, patients with damage to the hippocampus demonstrated a physiological arousal response to the blue square. However, they were not able to consciously recollect that it was paired with the shock (Bechara, et al., 1995). These results demonstrate that the hippocampal-dependent episodic representations of stimulus influence amygdala function. However, very little is known about exactly how an episodic representation alters amygdala function. This is because in general we have a relatively poor understanding of the precise mechanisms of storage for hippocampal-dependent memories, although it is likely that working memory plays an important part when an episodic memory is retrieved (Phelps, 2004).

Extinction of conditioned fear is an essential need for adaptive recovery from a traumatic experience and involves the unlearning of fear reaction to situations that were previously associated with negative outcome but currently can be considered as safe (Rothbaum & Davis, 2003). Research examining the neural systems of emotion regulation instructed participants to reappraise the emotional significance of a negative scene, by trying to interpret them as neutral or positive (Ochsner, Bunge, Gross, & Gabrieli, 2002). The strategy requires hippocampal-dependent memories to alter their response to the emotional stimuli. The findings indicate that this reappraisal strategy was successful in diminishing the reported emotional reaction and the amygdala response. Extinction of conditioned fear is an essential need for adaptive recovery from a traumatic experience impaired extinction of fear is a major clinical characteristic of PTSD (Rothbaum & Davis, 2003). Imaging studies with military veterans have established a relatively consistent association between hippocampal volume reduction and impaired memory functioning in individuals diagnosed with PTSD (e.g., Douglas, 1995; Gilbertson, et al., 2002; Gurvits, et al., 1996). Building on these findings, research with elite combat paramedic recruits found increased activation after stress relative to before stress in the amygdala and hippocampus, solely in response to stress-related medical content (Admon, et al., 2009). A follow-up study with the same participants post-combat found that those with increased PTSD symptoms had reduced hippocampus volume (Admon, et al., 2013). These findings provide further evidence of the involvement of the hippocampus in emotion regulation and how the chronic stress of combat structurally damages the hippocampus.

Ventromedial prefrontal cortex (vmPFC). The vmPFC is involved in executive function and decision-making, particularly the regulation of emotional conflict (Etkin, et al., 2011). Research examining the vmPFC is fueled in part by well-studied single cases like Phineas Gage (Eslinger & Damasio, 1985). Patients with vmPFC damage commonly display poor judgment, socially inappropriate behaviour and impulsivity (Berlin et al., 2004). Research comparing patients with vmPFC damage and healthy controls decision making on a gambling task has demonstrated this impulsivity (Bechara et al., 1994, 2000). In this research participants were asked to choose cards from ‘risky’ decks, that result in gradual debt over time, or cards from ‘safe’ decks, which result in a small overall profit. The results found that patients with vmPFC damage were driven by the short-term benefits of the risky deck and failed to learn an advantageous strategy (Bechara et al., 1994, 2000). In contrast, research with controls examining conflict monitoring found that when conflict is detected a regulatory system, involving the PFC and dorsal anterior cingulate cortex (dACC), is engaged biasing behaviour toward the goal-relevant response while suppressing incompatible responses (Kerns, et al., 2004).

The vmPFC has also been the focus in research examining the neural systems of fear extinction in nonhuman animals (e.g. Lebron, Milad, & Quirk, 2004; Morgan, Romanski, & LeDoux, 1993; Quirk, Russo, Barron, & Lebron, 2000). It was first implicated when Morgan et al. (1993) demonstrated that lesions in the vmPFC led to an impairment in fear extinction. Fear conditioning or the expression of conditioned fear in healthy humans has been associated with increased activation in the vmPFC (Phelps, Delgado, Nearing, & LeDoux, 2004). In contrast, fear extinction deficits have been shown to play a role in PTSD, with several studies reporting significant negative correlations between vmPFC activation and PTSD symptom severity (reviewed in Hughes & Shin, 2011).

Insular cortex. The insula cortex is a large region linked to numerous functions relevant to decision making, including the anticipation of pain (e.g. Ploghaus et al. 1999) and representation of risk (for review, see Kacelnik & Bateson, 1996; Knutson & Bossaerts, 2007; Weber, et al., 2004). fMRI based research employing the Risky-Gains decision making task (Paulus, et al., 2003) found that the insular activation was stronger when participants chose risky alternatives versus safe alternatives, this degree of insula activation was related to the subjects' degree of harm avoidance, a measure of 'risk-aversion' (Paulus, et al., 2003). Specifically, participants with increased activation in the right anterior insula during punished trials were more likely to score high on harm avoidance and neuroticism.

Insula activation occurs in a wide variety of task conditions for example, fMRI studies have shown insula related activation during the processing of faces. Research by Paulus, et al., (2010) compared behavioural performance and brain activation between US Navy SEAL (Sea-Air-Land) Commandos and a non-military control group while completing a face processing task (Paulus, et al., 2010). In this study participants were presented with a target face and two probe faces, responding via a button press participants were instructed to match the probe with the same emotional expression to the target. Behaviorally, there were no group differences in reaction time or accuracy; however, there was a significant group-by-emotion interaction with Navy SEALs slower to respond to happy and fearful faces than angry faces. This group by face interaction was also found in the fMRI data. Results revealed a significant percentage signal change in the insula cortex (relevant to decision making). Specifically, a significantly greater percentage signal change in the right insula, but an attenuated percent signal change in the left insula (see *Figure 1.2.*) in SEALs when presented with threat-related (angry) facial expressions compared to non-threat related (happy, fearful) facial expressions. These findings suggest that rather than expending more effort in general, SEALs show more focused neural and performance tuning, conserving processing resources when facing a non-threat stimulus.

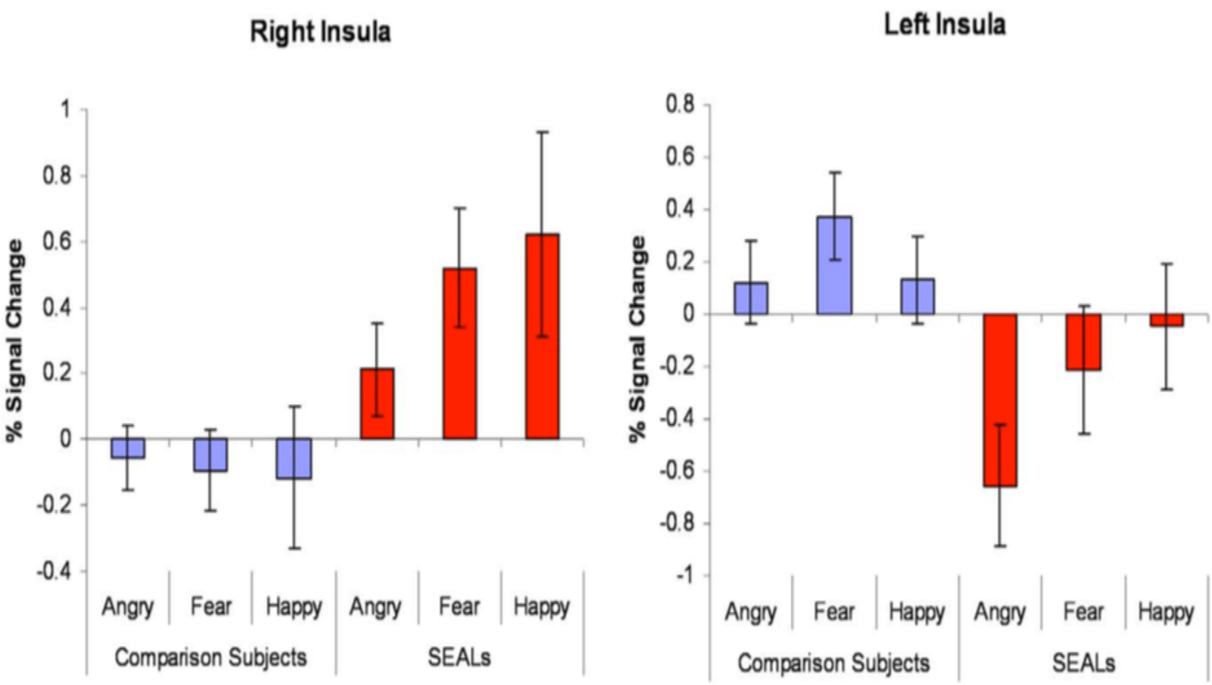

Figure 1.2. - Overall group differences showed relatively greater right insula activation in SEALs versus left insula activation in comparison subjects (Paulus, et al., 2010).

Building on this research, Simmons and colleagues (2011) examined task switching using fMRI, comparing Navy SEALs with a non-military control group. The study used a selection of positive images from the International Affective Picture System (IAPS) and a selection of negative combat relevant images. Participants were primed with either a green shape and 250hz tone or a red shape and a 1000Hz tone indicating whether the shape would be proceeded by a positive or negative image. The prime was then either preceded by the stimulus of matched valence or opposite valence. Their findings indicated that rather than being reactive to anticipatory stressors, Navy SEALs modulated emotional and interceptive processing (Phan, Wager, Taylor & Liberzon, 2002; Wagner, Phan, Liberzon & Taylor, 2003), when they were aware of a change in the anticipated situation (Simmons, et al., 2011). These findings provide further evidence of neural tuning in elite personnel.

In related research Morgan, Aikins, Steffian, Coric and Southwick, (2007) proposed a specific mechanism that may contribute to the maintenance of optimal performance in extreme environments. Specifically, Morgan (2007) suggested that decreased high-frequency variability in heart rate, which is modulated by the right insula (Oppenheimer, 2006). Increased activation in the right insula is associated with enhanced performance under high-stress conditions (Oppenheimer, 2006). These same pathways appear less active in individuals with PTSD symptoms as they attempt to modulate their physiology in advance of changing environmental conditions (Simmons, et al., 2009). This converging evidence suggests the insula is an important region for neurophysiological tuning, specifically relevant in emotional (Phan, Wager, Taylor & Liberzon, 2002) and anticipatory processing (Simmons, Matthews, Stein & Paulus, 2004; Simmons, Strigo, Matthews, Paulus & Stein, 2006) allowing individuals to be robust in extreme situations.

1.4. The Current Body of Research.

As noted, the present mental robustness research in a military context focuses either on mental robustness in relation to decision making (MRp component of robustness), with military recruits who have no combat experience; or research has focused on the negative health consequences associated with operational deployment. Further understanding of the neural processes involved in mental robustness is also lacking. Considering this, there is a gap in our understanding of how the vast majority of personnel are able to continue to perform during operational deployments without experiencing any negative health consequences. With these issues in mind, the present thesis had two broad aims. The first aim was to develop a psychometrically robust measure of mental robustness that was informant rated, relevant to military operations and assesses one’s ability to continue to perform under pressure and continue to perform when faced with the emotional challenges of combat. The second aim was to produce a better understanding of the relationship between activity in key brain regions, on the one hand, and key components of robustness, on the other hand. Together this approach will produce a deeper understanding of the underpinnings of mentally robust behaviour.

In order to achieve these aims we conducted a number of studies that are detailed in the following chapters. Chapter 2 discusses how best to develop a reliable and valid quantitative measure of mental robustness. Chapter 3 (Studies 1 and 2) describes the development and validation of a measure of mental robustness that is relevant to military operations. In Chapter 4, we discuss fMRI as a method and its potential usefulness in relation to mental robustness. Chapter 5 (Study 3) examines neural activity in experienced serving military personnel while completing an operationally relevant threat detection task and a simple decision-making task. In this study we examined the degree to which neural activity was related to informant rated scores of mental robustness and symptoms of PTSD. Finally, Chapter 6 – the general discussion, summarises the research findings of the PhD, then highlights the theoretical and applied implications of the research, the strengths and limitations of the thesis and recommendations for future research.

To provide an explanation for the format of this thesis it has been written in a style consistent with the policy of the School of Psychology and School of Sport, Health and Exercise Sciences at Bangor University wherein a short general introduction is used to set the scene for the reader which is then followed by two major empirical research papers and a general discussion. As the studies are separate but linked and have been written in the style of journal articles, it is sometimes necessary repetition across chapters, however, this has been minimised where possible.

Chapter 2

Developing a Reliable and Valid Measurement Instrument

2.1. Introduction

Developing sound measures is a difficult and time-consuming process (Schmitt & Klimoski, 1991). There are meticulous standards that need to be achieved in measurement development. A successful measure should demonstrate: *content validity* - how adequately does the measure assess the field of interest; *criterion-related validity* - relationship between the measure and another independent measure; *construct validity* - relationship of measure to the latent variable it is attempting to measure; *internal consistency* - extent to which item responses correlate with the total test score (American Psychological Association, 1985 as cited in Hinkin, 1995).

Self-report instruments are arguably the most popular instrument type (Cook, Hepworth, Wall & Warr, 1981; McDonald, 2008; Paulhus & Vazire, 2007). This is true of the field of mental robustness with much of the research relying almost exclusively on self-report measures. However, the use of self-report measures in the context of mental robustness is particularly problematic, given its ubiquitous standing as a socially desirable trait. Research within this field has progressed over the past decade, as such, alternative methods of assessing mental robustness, such as informant rated measures[1] are required to maintain the scientific integrity of the research. This is not to say that informant rated measures of

[1] Informant rated measures defined as inventories on which a target's superior, peers, friends, or acquaintances, for example, provide ratings that are based on their overall conception of the individual (McDonald, 2008).

mental robustness are not immune to demand characteristics particularly when used with military populations who want to maintain esprit de corps.

Keeping this in mind there are a number of steps necessary, from item development to confirming the measures factor structure on a secondary sample, to create a reliable and valid measure. This chapter will cover each of these steps.

2.2. Step 1: Item Development

The generation of items is arguably the most important part of measure development (Hinkin, 1995). The development process begins with the creation of items to assess a particular construct. Item development can take either an inductive or deductive approach. The *inductive* approach is typically used when investigating an unfamiliar phenomenon where theory does not yet have a solid grounding. This approach sees items derived from expert's descriptions of the field of research. Conversely, *deductive* measure development requires an understanding of the relevant literature with items derived from a theoretical definition with an initial pool of items created with this definition in mind (Schwab, 1980).

It is important to ensure items are properly constructed, addressing a single issue, avoiding double-barrelled (e.g. He has been reprimanded and punished) or choice constructs (e.g. A "battle buddy" has been wounded in action or killed in action) to avoid confusion on the part of the respondents. The perspective of items should remain consistent in that items that assess behaviours should not assess effective responses or outcomes of behaviours (Harrison & McLaughlin, 1993). Finally, items should be worded simply and the language used familiar to the target respondents, this will help ensure items are understood as intended by the researcher resulting in meaningful responses.

Ideally, these items are then presented to a working group of experts within the field of investigation to ensure that items are appropriately phrased and relevant to the field of research (Grant & Davis, 1997). Clear definitions of these factors should be provided to facilitate the evaluation process. The working group should then be asked to rate the items for each category on *representativeness* - the degree to which the set of items reflect and operationalizes the factor with which they are associated; and *comprehension* - the extent to which they perceive each individual item to be representative of the factor with which it is associated. Finally, the clarity of each items construction and wording should be reviewed to ensure there were no ambiguous or poorly written items. Based on their feedback, items that are perceived incongruent with its nominated factor could be assigned to an alternative factor with which it may be better matched, modified or removed entirely.

There are no specific rules regarding how many items should be retained. However, it has been said - “the best construct is the one around which we can be built with the greatest number of inferences, in the most direct fashion” (Cronbach & Meehl, 1955, p. 288). Previous research has indicated that adequate internal consistency and reliability can be obtained with four or five items per factor (Harvey, Billings, & Nilan, 1985; Hinkin & Schriesheim, 1989). While short measures can minimise response bias as a result of boredom or fatigue (Schmitt & Stults, 1985), it could be argued that the removal of a large number of items would inevitably result in a good model fit as this would result in fewer degrees of freedom, we will return to this point later in the chapter.

2.3. Step 2: Questionnaire Design

Questionnaires should be clearly and simply formatted. Scaling of the items should be carefully considered if the measure is to generate sufficient variance for subsequent statistical analysis. The most widely used response format is the Likert scale (Likert, 1932) in which responses are ranked using five or seven levels with the data collected typically treated as interval (Allen & Seaman, 2007).

The retained items should then be presented to an appropriate population. It is recommended that an initial sample of data from or on (depending on instrument type) 150 individuals should be collected to reduce the item pool to a valid subset of items (Krzystofiak, Cardy and Newman, 1988). A second sample of data on or from 150 individuals should then be used to confirm the factor structure obtained with the first sample (Krzystofiak, Cardy and Newman, 1988). These sample sizes both meet the minimum sample size requirement (Guandagnoli & Velicer, 1988; Hinkin, 1995).

2.4. Step 3: Data Analysis

There are a number of different statistical software programmes available to conduct the analysis, such as Amos 7.0 (Arbuckle, 2005); LISREL 8.8 (Jöreskog & Sörbom, 2004), and M*plus* 7.0 (Muthén & Muthén, 1998-2015).

2.4.1. Methodological approaches to assess structural validity.

Structural equation modelling (SEM) a generic framework comprises of two approaches to model testing:

(1) *Multiple regression* concerned with relationships between predictor variables[2] and a criterion variable[3] (often referred to as SEM). Regression analysis assumes that the measurement model of exogenous constructs is not influenced by other variables and the structural model of directed (predictive) paths relating latent and/or manifested variables[4] (Marsh, et al., 2014).

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[2] Predictor variables are variables that are being used to predict some other variable or outcome.

[3] The criterion variable is the variable being predicted.

[4] A variable directly observed/measured or defined by a single indicator (although this may be an average of multiple indicators; Marsh, et al., 2014).

(2) *Factor analysis* concerned with finding a set of latent variables[5] that explains the common variance among a set of observed variables (Biddle, Markland, Gilbourne, Chatzisarantis, & Sparkes, 2001). Factor analysis techniques are most frequently used to determine the factor structure of underlying scores on a set of questionnaire items (Marsh, et al., 2014).

2.4.2. Examining the measures dimensionality.

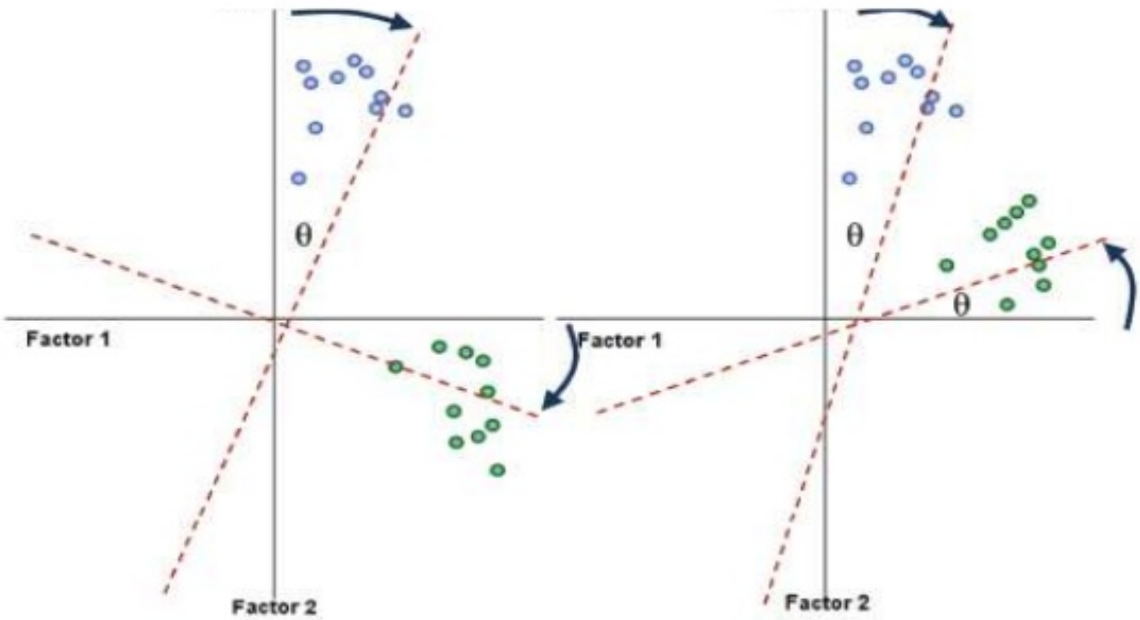
If researchers do not have a theoretical grounding regarding the dimensionality of the measure they are developing then they will need to use a technique that identifies clusters of variables. This can be done via exploratory factor analysis (EFA; Spearman, 1904, 1927) or principal components analysis (PCA; Cauchy, 1829; Pearson, 1901), as they are both linear models that aim to reduce a set of variables (DeCoster, 1998). EFA and PCA are often confused, however, while EFA determines the number and nature of latent variables by analysing the common variance, PCA analyses all the variance in the indicators to reduce the multiple observed variables into fewer components that summarise their variance. The key conceptual difference between EFA and PCA is that EFA produces factors that are thought to be the *'cause'* of the observed indicators, which provide a testable measurement model. Whereas PCA provides components that are '*outcomes*' built from linear combinations of the indicators. Essentially, the component is just the sum of the items and there is no inherent reason why the items correlate, they just do. As a result, there is not a testable measurement model because we do not know if the variables have been combined correctly.

2.4.3. Factor rotation.

An important feature of factor analysis is that the factors can be rotated within the multi-dimensional variable space. The discovery of miss-specified loadings is more direct

[5] A latent variable is an unobserved hypothetical construct

through rotation of the factor matrix than through the examination of model modification indices (Browne, 2001). Un-rotated results are typically more difficult to interpret. Conceptually, the axes are rotated so the factors fall closer to them simplifying the results of the factor analysis. In short, the strongest correlations between the items and the latent factor make up Axis 1 and the second strongest correlations make up Axis 2. To make the axis fit the actual data points better the axes is rotated. Rotation methods fall into two broad categories, (1) *orthogonal* rotations produce factors that are uncorrelated while (2) *oblique* rotations allow the factors to correlate (see *Figure 2.1*; Osbourne & Costello, 2009). Orthogonal rotations are often the default setting in most statistical packages. However, in multidimensional measurement development, we generally expect some correlation among factors as behaviour is rarely partitioned into neatly packaged units that function independently of one another.



Orthogonal Rotation Oblique Rotation

Figure 2.1. Schematic representations of factor rotation, the left graph displays orthogonal rotation whereas the right graph displays oblique rotation, θ is the angle through which the axis is rotated.

In summary, EFA should be employed when interested in making statements about the factors that are responsible for a set of observed responses. Considering this, EFA is an important precursor analysis to reveal the constructs underlying the measure before following up with a confirmatory factor analysis (CFA) with a separate data set (Cudeck & MacCallum, 2007). In the preliminary stages of theory development of a theories development and its associated instrumentation, this will often be the appropriate course of action (Jöreskog, Sörbom, & Magidson 1979). However, in most circumstances, today theory will be sufficiently advanced to justify a model testing approach (Biddle, et al., 2001).

2.4.4. Assessing Structural Validity

Assessing the structural validity of a theoretically grounded multidimensional measure typically sees researchers employ CFA using a maximum likelihood (ML) approach with a highly restrictive independent clusters model (ICM). This approach often results in the rejection of the model. Exploratory structural equation modelling (ESEM) provides an alternative far less restrictive approach to the ICM-CFA. An increasing and increasingly popular approach that has a number of advantages over ESEM is the Bayesian approach (Bayesian Structural Equation Modelling; BSEM) introduced by Muthén and Asparouhov (2012). The following paragraphs explore the evolution of the above approaches and their advantages and disadvantages.

2.4.5. Confirmatory factor analysis (CFA).

CFA is a technically appealing approach, as it requires researchers to formalise their measurement hypotheses and develop measurement instruments with a simple structure. A traditional ICM-CFA is characterised by using strict parameter constraints with fixed zero loadings using modification indices as guidance to improve the model by freeing parameters that strongly violate invariance. However, the number of zero loading restrictions is often far larger than the number of restrictions actually required (Asparouhov & Muthén, 2009). This can result in a more parsimonious model than is suitable for the data, leading to over-estimated factor correlations. Put simply, if a large number of small cross-loadings is restricted to zero then the correlations are artificially inflated (Marsh, et al., 2009). As a consequence, models are often rejected and extensive model modifications are undertaken to find a well-fitting model (Asparouhov & Muthén, 2009). Instances such as this see a more exploratory approach adopted to reduce and refine the measure before confirming the factor structure with a secondary data set (Browne, 2001).

Identification. As mentioned above an initial perfect model fit is rare. With an ICM-CFA there is more burden on the factor correlation to reproduce the correlation between indicators specified to load on different factors because there are no cross-loadings to assist in this model-implied estimate (Brown & Moore, 2012). As such, the ICM-CFA process employs a fitting function to minimize the difference between the sample and model-implied to maximise the probability of observing similar findings with a separate sample. The most widely used (and often default) identification or 'fitting' function is the 'maximum likelihood' (ML; Lawley, 1940), estimator. The goal is to maximize the likelihood function to find the solution with the largest possible log likelihood[6] value. Utilising an iterative procedure, the initial set of parameters is repeatedly refined in an effort to minimise the difference between the sample and model-implied variance-covariance matrices. When a set of parameter estimates cannot be improved upon any further (in that the difference between the input and predicted matrices cannot be further reduced), then convergence is assumed.

The ML function is highly sensitive to sample size and requires a large sample with the factors measured on a continuous scale. The distribution of the indicators should be

[6] The log likelihood value is a measure of the probability of the observed data given the model. It is used as the basis for calculating various fit statistics.

normal as non-normality can result in biased standard errors. In the case of non-normal continuous indicators, a different estimator such as ML with robust standard errors and goodness of fit statistics should be employed (e.g. Bentler, 1995). While ML allows for the specification of some cross-loadings and correlated residuals, this could lead to non-identified model if too many cross-loadings are allowed. Despite this, it is recommended that ML should be used unless the measure being tested lacks multivariate normality, in which case it is recommended that an asymptotically distribution-free (ADF; Guttmann, 1945) estimation should be used to fit the model to the data (c.f Browne, 1984).

Measuring model fit in CFA. Historically, researchers would rely on chi-square (χ^2) to degrees-of-freedom (*df*) ratios to interpret model fit (Thompson & Daniel, 1996). For models with approximately 75 to 200 cases, the χ^2 is a reasonable measure of fit. It should be noted that large sample sizes can artificially inflate these values, and models with 400 or more cases will result in an almost always statistically significant χ^2. In addition, there is no agreed upon standard as to what is a good and a bad fitting model, with some criticising it for being too liberal which can result in too many Type I errors. While reporting χ^2 and *df* helps the reader determine how the model was specified, reliance on this one test statistic to determine model fit can be problematic. As such, the model fit is rarely interpreted by solely the χ^2 instead a myriad of fit statistics in addition to the χ^2 should be evaluated and reported.

Available fit indices are mostly based on different theoretical rationales; from a practical point of view they are superficially similar (Fan, Thompson & Wang, 1999). The most widely accepted and reported goodness of fit indices are the standardised root mean square residual (SRMR), root mean square error of approximation (RMSEA), Tucker-Lewis index (TLI; Tucker & Lewis, 1973) and the comparative fit index (CFI; Bentler, 1990).

The SRMR is the square root of the difference between the residuals of the sample covariance matrix and the hypothesised covariance model. Values for SRMR range from zero to 1.0, an SRMR of zero indicates perfect fit, well-fitting models obtain values less than .05 (Bryne, 1998; Diamantopoulos & Siguaw, 2000). However, values as high as .08 are also deemed acceptable (Hu & Bentler, 1999). RMSEA measures the level of discrepancy between the theoretical and the empirical model according to the degrees of freedom. The theoretical model is considered well-adjusted when the value is smaller than .05, and reasonable when the RMSEA value is between .05 and .08 (Browne & Cudeck, 1993). TLI (also known as the non-normed fit index; NNFI) depends on the average size of the correlations in the data (as does the CFI described below). Therefore, if the average correlation between variables is not high, then the TLI will not be high. As with SRMR, this statistic ranges from zero to 1.0, however with the TLI values closer to 1.0 indicate a better fit. Interpreting the TLI is best done in conjunction with RMSEA. The CFI assumes that all the latent variables are uncorrelated and compares the sample covariance matrix with this null model. Like the TLI values range from zero to 1.0 and scores closer to 1.0 indicate a better fit. A CFI value of ≥.90 is required to ensure that miss specified models are not accepted, as such a value of ≥.95 is indicative of a good fit (Hu & Bentler, 1999). The CFI is one of the most frequently reported fit statistics as it is the least affected by sample size (Fan, Thompson & Wang, 1999). Each of these indices should be assessed to interpret the goodness of fit (cf. Brown 2015).

Model fit caveats. Fit indices are useful as they summarize model fit, however, good (or perfect) fit does not ensure that the model is correct, only that it is plausible. You can strengthen your model argument by testing alternative models such as a 'true' single factor model in which you load all items from both factors into a single factor analysis to see if convergence is achieved. If you can reject these models then you strengthen the argument that the developed model is valid. Another key point to remember is that values of fit indices depend critically on how many *df* are available in the final calculation to vary without violating any constraints imposed upon them. If there are no *df* then the model will fit perfectly as it is saturated with data, few *df* is likely to give a good model fit but there is little room for disconfirming the model. Ideally, there will be many *df*, the more *df* the more likely you are to get a poor model, however, in cases such as this, a good model fit is most impressive.

While there are many situations where a CFA approach may be preferred more flexible analysis techniques have been proposed for more complex measurement structures (Hopwood & Donnellan, 2010). Both ESEM and Bayesian estimation can alleviate concerns associated with ICM-CFA approach.

2.4.6. Exploratory structural equation modelling (ESEM)

ESEM provides a useful alternative to ICM-CFA by integrating the best aspects of EFA and CFA. It incorporates all combinations by allowing non-zero cross-loadings and rotation of factor matrices, while also providing standard errors for the parameters and conventional fit indices (Niven & Markland, 2016). One of the advantages of ESEM modelling is that small cross-loadings do not need to be eliminated from the model; in CFA analysis such loadings are typically fixed at 0. This allowance of small cross-loadings more realistically represents respondent data by accounting for both imperfect indicators and social desirability responding (Ng, Cao, Marsh, Tay, & Selgiman, 2016). However, ESEM does not allow specification of how close to zero cross-loadings should be, nor does it allow for correlated residuals (Muthén & Asparouhov, 2012). Like CFA all parameters in ESEM are identified with the ML estimator discussed earlier in the chapter.

Rotational Indeterminacy. As with EFA the pattern of cross-loadings and the size of the estimated factor correlations vary with the specific rotation (e.g., Browne 2001, Sass & Schmitt 2010). Mechanical rotation methods (e.g., Quartimin, Geomin) are used to approximate a simple factor structure. However, there are no clear guidelines as to which rotational method should be employed when, and to some extent, it is still an open research area. Quartimin is both algebraically and conceptually the simplest general method of rotation (Jennrich & Sampson, 1966). However, simulation studies have indicated that geomin is best suited for simple to moderately complex loading matrix structures, as it will fail with matrix structures involving three or more factors with three or more non-zero loadings (Asparouhov & Muthén, 2009). In cases such as this, target rotation would be more appropriate where cross loadings are estimated under the restriction that their values are as close as possible to zero (Niven & Markland, 2016). Unlike quartimin and geomin, target rotation is thought of as "*a non-mechanical exploratory process, guided by human judgment*" (Browne, 2001, p. 125). Target rotation was designed to rotate the pattern matrix to a solution that is closest to a targeted pattern matrix. This allows some control over the specification of the model where incomplete a priori substantive measurement theory is available and a complex underlying structure is likely (Myers, Ahn, & Jin, 2013). Considering this conceptually, target rotation is situated between CFA and EFA (Asparouhov & Muthén, 2009).

Model fit in ESEM. As with CFA model fit can be assessed by χ^2 using the likelihood ratio test (LRT) to compare the structural model against an unrestricted mean and variance model. Approximate fit indices such as SRMR, CFI and TLI (described earlier) can be reviewed to evaluate the fit of the model.

ESEM is primarily a confirmatory tool, but like traditional EFA it can be used with appropriate caution as an exploratory tool. It has a number of advantages over EFA, in particular, you do not need to move from EFA to CFA when wanting to study measurement invariance (cf. Morin, Marsh, Nagengast, 2013).

Disadvantages of ESEM. ESEM takes a frequentist statistical approach and repeatedly tests the same null hypothesis. This is because ESEM utilises the ML estimator, which views parameters as constants (Yuan & MacKinnon, 2009), as such ESEM does not allow for correlated residuals (Muthén & Asparouhov, 2012). An approach that views parameters as variables with a mean and a distribution of values (rather than as constants) is the Bayesian approach to SEM. This Bayesian SEM (BSEM) rationale is similar to the target rotation with ESEM, however, it overcomes the limitations associated with correlated residuals.

2.4.7 Bayesian structural equation modelling.

BSEM has recently been considered an alternative approach to CFA and SEM and is beginning to be adopted in the sport and exercise psychology literature (Barnettm, Vazou, Abbott, Bowe, Robinson, Ridgers & Salmon, 2016; Gucciardi & Jackson, 2015; Gucciardi, Peeling, Ducker, & Dawson, 2016; Jackson, Guicciardi, & Dimmock, 2014; Strenling, Ivarsson, Johnson, & Lindwall). This analysis provides a more flexible approach to assessing structural validity. The primary goal of estimating a BSEM model is not to confirm or refute the CFA model but rather discover the places where the CFA model fails (Asparouhov, Muthén & Morin, 2015). In essence, the focus of this approach is not only to test the model but to generate ideas about possible model modifications that can yield a better fitting model.

By utilising a Bayesian approach more can be learned about the parameter estimates and model fit than can be learned with other analysis techniques such as CFA or ESEM. The BSEM employs approximately zero parameters using zero-mean, small-variance informative priors. Essentially, BSEM approach provides a tool for detecting non-invariance that serves the same purpose as modification indices with ML estimation. However, while ML finds estimates by maximizing a likelihood computed for the data, Bayesian tools allow for intuitive interpretations. It does this by combining prior distributions for the data likelihood to form posterior distributions for the parameter estimates (Muthén, 2010). It serves as a tool for estimating a range of estimates wherein one true parameter which would appear 95% of the time if a study were to be conducted an infinite number of times (Gucciardi & Zyphur, 2016). Considering this, while parameters inside the 95% confidence interval provide information about the parameter, values outside the 95% confidence interval provide information on what the parameter is not.

Degrees of (un)certainty associated with prior expectations is often ignored in ICM-CFA when employing ML estimations, essentially a frequentist approach sees the null hypothesis tested over and over again (van de Schoot, et al., 2014). This can result in models being computationally cumbersome or impossible due to many dimensions of numerical integration. In contrast, Bayesian estimations are concerned with the probability that a hypothesis is true given the data by allowing probabilistic information about parameters to be incorporated into the analyses as a cumulative progression of knowledge (Zyphur & Oswald, 2013).

Prior Distributions. The prior probability represents researchers background knowledge of the parameter before observing the data as such a smaller variance reflects higher certainty and vice versa (Van de Schoot et al., 2014). There are three categories of prior probability: (1) *non-informative priors* which reflect substantial uncertainty in the researchers expectations of the nature of the parameter and do not influence the final results; (2) *weakly informative priors* incorporate some prior knowledge regarding the population parameter and do not substantially influence the final parameter estimate in the posterior distribution once combined with the data; and (3) *informative priors* which reflect a great deal of certainty in the population parameter and are highly influential for final estimates (van de Schoot et al., 2014). Bayesian estimation with non-informative priors yields almost identical results as ML estimation (Muthén & Asparouhov, 2012). An advantage of priors is that researchers can continuously incorporate new knowledge into their analysis instead of relying on null hypothesis significance testing (van de Schoot et al., 2014).

Cross loadings and residual covariance's in BSEM. CFA hypothesises that an item can only load onto one specific factor, a more realistic approach might be to consider that each item has a primary factor but may cross-load between items and non-target factors onto another factor to a small degree (Muthén, 2010). BSEM approach has the ability to simultaneously estimate all possible cross-loadings and residual covariance's[7], present in the model that may be meaningful. This is not possible if ML estimation is applied (Muthén & Asparouhov, 2012). Both of these approaches involve adding to the model a set of potentially miss specified parameters. These parameters are neither completely fixed to zero (like CFA) nor are they completely free (like EFA), instead they are approximately fixed to zero (Asparouhov, Muthén & Morin, 2015). Uniquely, by employing a BSEM approach the hypothesised SEM model is preserved while simultaneously allowing the data to drive away from zero some of the additional parameters when evidence in the data exists (Asparouhov, et al., 2015).

It has been argued that modelling cross-loadings with priors are akin to 'modelling noise' and researchers shouldn't want to develop instruments that include cross-loadings (Stromeyer, Miller, Sriramachandramurthy, & DeMartino, 2015). In reality, it is rare that a factor is a perfectly 'pure' indicator of a latent variable. Instead of considering small cross loadings as adding noise and tainting the data they should actually be viewed as allowing the

[7] Residual covariance's model shared sources of influence on the indicators that are unrelated to the factors

latent variable to be estimated using all of the relevant information present at a factor level. Results from simulated studies (e.g., Asparouhov & Muthén, 2009; Sass & Schmitt, 2010; Schmitt & Sass, 2011) and studies based on simulated data (e.g., Marsh, Lüdtke, Nagengast, Morin, & Von Davier, 2013) have demonstrated that Stromeyer's (2013) argument against cross-loadings is flawed by showing that it is the exclusion of these cross-loadings that modifies the meaning of these latent variables, not the other way around.

Variable estimation and convergence. The popularity of the Bayesian approach is partly due to the success of the computational algorithms referred to as Markov chain Monte Carlo (MCMC) simulation procedures (Muthén, 2010). Latent variables are estimated in M*plus* by employing the MCMC algorithm. The algorithm measures the error in a continuous mediator on the causal indirect and direct effects for a binary outcome. Convergence in the MCMC sequence is not always easy to diagnose, as such M*plus* provides trace and auto correction plots for the parameter estimates as well as proportion scale reduction (PSR; Gelman & Rubin, 1992). PSR is employed as the default criterion to determine if convergence has occurred by comparing up to several MCMC sequences (two by default). Briefly, PSR uses variation in parameter estimates over multiple iterations between chains versus total parameter variation over multiple iterations to assess convergence. Evidence for convergence is shown when the PSR value lies between 1.0 and 1.1 (Gelman, Carlin, Stern, & Rubin, 2004). It is recommended that 100,000 iterations are specified for each of the two MCMC. The first 50,000 iterations should be discarded as part of the 'burn-in' period; the second 50,000 form the posterior distribution and are used to evaluate convergence.

To avoid premature convergence determination by PSR the Kolomogorov-Smirnov (K-S; Kolomogorov, 1933; Smirnov, 1939) test should be employed. The K-S test assesses convergence and indicates if there are any significant differences between the posterior distributions across the MCMC chains. It is recommended that trace plots for each parameter be visually inspected to assess the stability of the means and variance across the MCMC chains. It has been argued that the K-S test might actually be a better all-round test of model fit than the χ^2 test (Massey 1951).

Sensitivity analysis. Researchers are encouraged to perform a sensitivity analysis to understand the influence of priors on posterior distributions when there is some degree of subjectivity in the choice of priors, or when sample size is small (van de Schoot et al., 2014; Zyphur & Oswald, 2013). The specification of smaller (.005) and larger (.015) prior variances may influence the posterior predictive *p* value and increase the variability of estimates (Muthén & Asparouhov, 2012). In turn, it allows researchers to assess the stability of the findings and check for any important discrepancies by comparing them to prior specifications.

Model Fit in Bayesian analysis. Bayesian exploration of model fit can be done in a flexible way using posterior predictive checking (PPC). The posterior distribution generated by a model is compared with the observed data; if the replicated and observed data closely match then an acceptable model fit can be assumed (Muthén & Asparouhov, 2012). M*plus* output produces the posterior predictive *p* value (*PPP*-value), an indicator of the posterior distribution. Values $\geq .50$ indicate a well-fitting model, whereas small values (e.g., $<.05$) suggests poor model fit (Muthén & Asparouhov, 2012; Zyphur & Oswald, 2013).

Model fit can also be assessed by the deviance information criterion (DIC) a hierarchical modelling generalisation of the Akaike information criterion (AIC; Akaike, 1973,1974) and the Bayesian information criterion (BIC; Schwarz, 1978). While it is possible to improve model fit by adding parameters, this can result in overfitting and thus poor predictive performance. The AIC and BIC resolve this problem by utilizing a penalty term for the number parameters in the model. The AIC is a measure of the relative quality of each statistical model by dealing with the trade-off between the model's goodness of fit and the complexity of the model. The BIC is closely related to the AIC but penalises free parameters more strongly than the AIC. Lower AIC and BIC score implies fewer explanatory variables, better fit, or both.

Disadvantages of BSEM. BSEM estimates are heavily theory driven, such that informative priors do not allow the estimates to differ substantially from expected values, so BSEM is not a final solution under these circumstances. While ESEM is an extension of the traditional latent variable framework that incorporates EFA factors, Bayesian estimation is fundamentally different probability calculus. Unlike the frequentist approach Bayesian estimation permits the explicit integration of prior knowledge with new data thereby providing results that represent a revised or updated condition (Zyphur & Oswald, 2013). It is important that the flexibility of these techniques does not come at the cost of sound instrument development or parsimonious models (Gucciardi and Zyphur, 2016).

2.5. Step 4: Construct Validity

Establishing the measures construct validity is typically done by examining the measures convergent validity (discussed earlier). This can be done by examining the extent to which the developed measure correlates with existing measures designed to assess similar constructs and discriminant validity (i.e. the extent to which the developed measure does not correlate with dissimilar measures). In relatively understudied or obscure fields of interest, such as the present, this approach is not possible. On occasions such as this, construct validity can be examined by reviewing the extent to which the first data set correlates with the second data set. Ideally, both data sets should demonstrate a good model fit, while still able to discriminate between different populations.

2.6. Conclusion

Good research begins with good measurement. As new and exciting research methods are developed there has been an increasing gap between these approaches and the advancement of appropriate statistical methodology. Increasing focus on analysis techniques, particularly within the sport and exercise literature (Niven & Markland, 2016), has demonstrated the superiority of new statistical tools (e.g. BSEM) over more traditional approaches (e.g. CFA). However, there still seems to be some difficulty in fostering methodological-substantive synergy (Marsh & Hau, 2007), and researchers should choose their model testing strategies with care.

Mental robustness is a complex psychological concept and therefore it is important to select the appropriate analysis technique particularly when attempting to develop a new measure that looks to tap two subscales of the same concept. As described earlier in this chapter, BSEM provides a number of advantages over its frequentist counterparts. In BSEM models, small but potentially influential cross-loadings and residual correlations can be estimated in a single analysis, which often produces a well-fitting model and a better reflection of substantive theory (Muthén & Asparouhov, 2012). Also, factor correlations are often overestimated in ML-based CFA models with zero cross-loadings (Asparouhov & Muthén, 2009). This would be particularly problematic in the current research as we are developing a measure that assesses two closely related aspects of mental robustness. Overestimated factor correlations can lead to multicollinearity problems, which can lead to misleading and un-interpretable results (Marsh, 2007). A BSEM approach, which allows small-variance priors on cross-loadings and residual correlations, may present a solution to such problems. Considering this, a Bayesian approach has been adopted for the assessment of factorial validity within the development of a new measure of mental robustness.

Chapter 3

Measuring Mental Robustness on Military Operations (MR-MO) with UK Armed Forces

3.1. Abstract

We conducted two studies to develop and validate an informant-rated multidimensional measure of mental robustness relevant to military operations. Study 1(n = 24 informants reporting on 199 Royal Marine Commandos) focused on item development and the structural validity of the measure of Mental Robustness for Military Operations (MR-MO) using Bayesian Structural Equation Modelling (BSEM). This multidimensional measure assessed the ability to maintain optimal performance under pressure and the ability to function effectively during emotional challenges experienced by military personnel, trained in ground close combat, while deployed on operations in conflict zones. BSEM analyses revealed that, following item removal, a 12-item measure provided an acceptable model fit. Study 2 (n = 26 informants reporting on 137 Army personnel) provided confirmation of the two-factor structure of the MR-MO again using BSEM. Further, in Study 2 we provided initial evidence of construct validity of the measure, as the different components of mental robustness measured by the MR-MO discriminated between military personnel of different services. Overall, the MR-MO displays sound psychometric properties and is the first multidimensional measure of robustness that is relevant to military contexts.

3.2. Introduction

Everyone experiences at least one potentially traumatic event in their lifetime (Kessler, Sonnega, Bromet, Hughes, & Nelson, 1995). Indeed, within military settings, an estimated 4% of regular UK Armed Forces (UK AF) personnel are affected by post-traumatic stress disorder (PTSD; Fear, et al., 2010). While this is a substantial number, it is also evident that the majority of military personnel are able to perform effectively in the face of such adversity and are not affected by such problems. Thus, understanding the factors that influence how an individual is able to perform to a high standard and cope with the demands of the situation while under extreme operational stress is vital. One such factor may be mental robustness.

In the present work, we focus on one factor that might be protective against traumatic experiences, namely mental robustness. We define mental robustness as the ability to continue to thrive in the face of potential trauma and distinguish this from “mental resilience” one’s ability to bounce back from breakdown induced by traumatic events (Smith, Dalen, Wiggins, Tooley, Christopher, & Bernard, 2008). In this manuscript, we offer a two dimensional conceptualisation of mental robustness and develop an informant-rated measure of the construct. This work is part of a wider program of research investigating the neurocognitive underpinnings of mental robustness in United Kingdom Armed Forces (UK AF) personnel, and the relation between mental robustness and military personnel’s mental health. The overarching aim of the wider project is to produce a working neurocognitive model of the different dimensions of mental robustness. This measurement development manuscript represents the first stage of this work.

Mental robustness is important in many areas of life such as sport, business and the military (Clough & Strycharczyk, 2012). However, given the multiple and varied stressors that military personnel face on a daily basis (in training and on operations) military settings provide an ideal medium through which to examine the role of mental robustness. Military personnel have "…to operate in stressful situations involving complex environments, high degrees of uncertainty and time pressure, and severe consequences for mistakes…" (Baumann, Gohm, & Bonner, 2011 p.548). Individuals who undertake dismounted ground close combat roles have been identified to be at the highest risk of suffering from post-traumatic stress symptoms (PTSS; Fear, Jones, Murphy, Hull, Iversen, et al., 2010; Jones, Sundin, Goodwin, Hull, Fear, et al., 2012; Rona, Hooper, Jones, Iversen, Hull, et al., 2009). Therefore, understanding factors that contribute to and affect mental robustness is important for military organizations and for personnel returning to civilian life (Adler, Possemato, Mavandadi, Lerner, Chang, et al., 2015). For personnel to cope effectively with the stresses associated with modern operations their psychological robustness must be optimal allowing personnel to not only be *fit for action* but also *fit for life* (Kamphuis, Venrooij, & Berg, 2006).

In recent years a number of measures of mental robustness (often referred to as 'mental toughness' a term that describes a vast constellation of variables, one of which is mental robustness) have been developed. These include the Mental Toughness Questionnaire – 48 (MTQ-48, Clough, Sewell, & Earle, 2002), the Mental Toughness Inventory (MTI, Middleton, Marsh, Martin, Richards & Perry, 2005), and within sport, the Sport Mental Toughness Questionnaire (SMTQ, Sheard, Golby & Van Wersch, 2008) and Cricket Mental Toughness Inventory (Gucciardi & Gordon, 2009). While the development of these measures has contributed to the literature on mental robustness, it is apparent that these measures assess a wide array of values and cognitions as opposed to explicitly capturing robust *behaviour*. Indeed, while values and cognitions may influence robustness, mental robustness is best assessed in terms of the presence or absence of a behavior, as robust values and/or cognitions may not necessarily lead to robust behavior or may simply be correlates of mental robustness (see Hardy, Bell, & Beattie, 2014 for detailed coverage of this issue). Further to this issue of what is actually being assessed, most of the aforementioned measures are self-report. Although self-report measures are commonplace across much of psychology, the use of self-report measures in the context of mental robustness is particularly problematic given its ubiquitous standing as a socially desirable characteristic (Hardy et al., 2014). Thus, for measures of mental robustness to be appropriate they need to move away from self-report to informant report and focus on behaviours as opposed to cognitions. Historically, informant ratings of behaviour have been underutilised within psychology because of researchers' outdated beliefs that informant data are not accurate and are burdensome to collect (see Vazire, 2006 for more on this issue). Not only are informant ratings simple to collect, they are more reliable than self-ratings (Balsis, Cooper, & Oltmanns, 2015) and do not suffer from the same social desirability issues that pervade self-report measures, which is particularly prominent in the case of mental robustness (see Roberts & Woodman, 2015). However, this is not to say that informant rated measures of mental robustness are not immune to demand characteristics particularly when used with military populations who want to maintain a level of esprit de corps. More recently, two studies have begun to consider mental robustness using informant ratings.

Hardy et al. (2014) developed an informant-rated behavioural measure of mental robustness that examined an individual's "…ability to achieve personal goals in the face of pressure from a wide range of different stressors" (p5) in high-level sport. Importantly, this measure assessed whether robust behavior had occurred or not by asking coaches to rate their athletes e.g. "His/her preparation has not gone to plan". The measure developed by Hardy et al., (2014) displays appropriate factorial validity and construct validity and has also been used to examine the effects of successful mental robustness interventions (e.g., Bell, Hardy, & Beattie, 2013) and predicting mental robustness in high-level sport (e.g. Beattie, Alqallaf

& Hardy, in press). Because of its sport focus, Hardy et al.'s (2014) measure does not map onto the military environment. However, it was more recently adapted for the military domain by Arthur, Fitzwater, Hardy, Beattie, and Bell (2015). Arthur et al. focused on the ability to maintain optimal performance under pressure from a range of stressors experienced during recruit training and developed the Military Training Mental Toughness Inventory (MTMTI) across three studies. The MTMTI demonstrated good psychometric properties and was able to predict a number of military relevant behavioural outcomes.

Although these studies represent an important step forward in the measurement of mental robustness, two major lacunae, especially in relation to military environments, remain apparent. First, the existing military measure (the MTMTI) only assesses mental robustness during training. Thus, the relevance of this measure in predicting operational performance is questionable. Second, and more broadly, all the current extant measures of mental robustness take a unidimensional perspective, by focusing on decision-making and motor control under pressure, to the exclusion of other aspects (e.g., emotional challenges that may affect the robustness of performance), which may be particularly important in military contexts. Effective decision-making and motor control are undoubtedly key aspects of mental robustness in many domains. A unique characteristic of the military, particularly during operations, that is not as present in other domains (such as sport) is the requirement to effectively manage emotionally traumatic situations (e.g., seeing friends and comrades killed or seriously wounded in action), which can have a lasting impact on military personnel's mental health (Solomon & Mikulincer, 2006). The ability to successfully negotiate such emotional challenges constitutes another major dimension of mental robustness, one whose psychological and neural underpinnings likely differ from those involved in maintaining task performance during adversity, that has yet to be captured by existing measures of the construct. In a similar strain, research by Chen, Wang and Yan (2015) developed a multidimensional measure of mental resilience that examined, *physical impacts* (e.g. extreme hunger, severe thirst and long working hours), *emotional life events* (e.g. lost a loved person, suffering from distress) and *socially adverse events* (e.g. being wronged, dealing with strict persons). This research speaks to the debate that traits such as mental resilience and possibly mental robustness are multi-faceted and are better captured through multi-dimensional scales.

The present work tests the theoretical stance that mental robustness is characterised by two dimensions (1) the ability to continue to perform to a high standard while effectively making decisions based on complex ques that have meaningful consequences (henceforth mental robustness pressured performance or “MRp”) and (2) the ability to continue to perform even when faced with challenging emotional experiences (henceforth “MRec”). In this conception, the two dimensions of mental robustness share in common the need to effectively handle negative or challenging contexts or events (e.g. pressure, trauma). However, an essential difference is that while MRp is more related to our role as *an agent* of events, MRec is more related to our role as a *subject.*

Given that an appropriate measurement instrument tapping multiple components of robustness does not exist, the focus of the current research was to develop a psychometrically valid measure (Hinkin, Tracey, & Enz, 1997) of mental robustness that was (a) informant-rated, (b) relevant to occupational performance during military operations, and (c) assessed aspects of mental robustness pertinent to MRp and MRec. This was achieved across two studies. Study 1 involved item development, scale refinement and initial testing of the factorial validity of both subscales with using Bayesian Structural Equation Modelling (BSEM) in a sample of Royal Marine Commandos (RM). Study 2 tested the structural validity of the refined questionnaire that emerged from Study 1 in a sample of Army personnel, and also provided an initial test of construct validity.

Study 1

3.3. Method

We obtained ethical approval from the Ministry of Defence Research Ethics Committee (MoDREC) as well as institutional ethical approval.

Stage 1: Item development. In this initial stage, we generated items to measure MRec and MRp respectively. For MRec we created an initial item pool of 17 operationally relevant items. Further, we used specific terminology to allow for the measure to be relevant for both past, present and future operational environments by mirroring the language used in the military model of expeditionary warfare (e.g., we used ‘Allied Nations’ instead of ‘Coalition Forces’). We presented the items to a working group of experts in robustness and performance (*n* = 4 well respected Research Professors in Sport Psychology) and serving operationally experienced military personnel (*n* = 6). The working group reviewed them for readability, redundancy and overall content representativeness (See Appendix A for feed back from the military steering group). Four items were not considered relevant and/or comprehensible by one or more of the 10 reviewers and were deleted from the pool, and four were modified based on the reviewing process.

To create operationally relevant MRp items we adapted the eight items of the MTMTI (Arthur et al., 2015) to make them operationally relevant. For example, the item ‘The conditions are difficult (e.g., on exercise)’ was changed to ‘The conditions are difficult (e.g., on patrol/ deliberate operations)’. Two additional items were developed resulting in a pool of 10 items relevant to MRp.

We combined these with the 13 MRec items resulting in a 23-item informant-rated measure of mental robustness for military operations. Informants were asked to rate personnel who served under them on their most recent operational tour using the stem "*Based on my observations of Soldier ‘X’ while on an operational deployment, Soldier ‘X’ is able to* *maintain a high level of personal performance, even when:"* Responses were based on a 7-point Likert scale that ranged from 1 ("*never"*) to 7 ("*always"*), with a midpoint anchor of 4 ("*sometimes"*), a '*not applicable'* option was also available as it was instructed that responses should be based on actual experiences.

Stage 2: Structural Validity. The purpose of Stage 2 was to test the factor structure of the measure of mental robustness for military operations (MR-MO) using BSEM. The traditional approach to assess the factorial validity of theoretically grounded multidimensional measures is to employ confirmatory factor analysis (CFA) using a maximum likelihood (ML) approach. However, this approach applies unnecessary and unrealistic model constraints with inappropriate exact zero cross-loadings and residual correlations. In reality, the factor structure of most models is more complex with many small cross-loadings (Muthén & Asparouhov, 2012). An alternative approach to ML-CFA is exploratory structural equation modelling (ESEM; Asparouhov & Muthén, 2009) which incorporates aspects of exploratory factor analysis (EFA) and CFA. As with EFA, ESEM allows non-zero cross-loadings and rotation of factor matrices, while also providing standard errors for the parameters and conventional fit indices like CFA. However, ESEM does not allow specification of how close to zero cross-loadings should be nor does it allow for correlated residuals (Muthén & Asparouhov, 2012).

In contrast, the BSEM approach employed in this research is strictly confirmatory in nature and less restrictive than ML-CFA. BSEM benefits from being a less restrictive approach as it allows simultaneous estimation of all cross-loadings and residual correlations in which *approximate* zero informative priors are employed to replace the exact zeros for the cross-loading and residual correlations in ML-CFA. In addition, BSEM is a better estimator of small sample performance as it accommodates skewed distributions of parameter estimates and does not rely on large sample normal theory (Muthén & Asparouhov, 2012). The BSEM approach is quickly becoming the preferred approach for the assessment of factorial validity in scale development and testing, and is gaining popularity in the psychological and social sciences (e.g., Gucciardi & Zyphur, 2016; Niven & Markland, 2016; Stenlin, Ivarsson, Johnson, & Lindwall, 2015).

3.3.1 Participants.

A total of 199 Royal Marine Commandos (RM: elite amphibious fighting force) were reported on by 24 male RM non-commissioned officers. Informants were aged between 22 and 44 (M_{age} = 31.36, *SD* = 4.81) and had served in the Royal Marines from 5 to 25 years (M = 12.63, *SD* = 4.07). All informants had deployed on operations with at least one operational deployment in the past five years (M = 2.91, *SD* = .78) in ground close combat roles defined as "combat with the enemy over short range on the ground" (Cawkill, Rogers, Knight, Spear & West, 2010, p.9). Service ranks ranged from Lance Corporal (NATO Code OR-3) to Warrant Officer Class II (NATO Code OR-8). Informant's reported educational attainment ranged from General Certificate of Secondary Education (GCSE; UK equivalent of the High School Diploma) to Bachelors degree, with 59 percent of informants attaining at least GCE Advanced Level. We removed data from six RMs due to incomplete questionnaires leaving data on 193 RMs subject to analysis. This sample size meets the widely accepted minimum sample size criteria (Guandagnoli & Velicer, 1988; Hinkin, 1995). Informants reported on between 2 and 12 (M = 9.85, *SD* = 3.69) RMs each.

3.3.2 Instruments.

Mental Robustness. We used the 23-item MR-MO described above to measure mental robustness.

Post-Traumatic Stress. As individuals exposed to trauma are susceptible to altering their retrospective reports of events (McNally, Lasko, Macklin, & Pitman, 1995; McNally, Litz, Prassas, Shin, & Weathers, 1994; Schwarz, Kowalski, & Mcnally, 1993), we were concerned that Post-Traumatic Stress Symptoms (PTSS) may affect informant ratings. Thus, we screened for PTSS in the informants using the PTSD Checklist-Military (PCL-M; Weathers, Huska, & Keane, 1991). This 17-item self-report measure assesses the DSM-IV symptoms of PTSD. Responses are based on a 5-point Likert scale that ranged from 1 (*"not at all")* to 5 *("extremely"*) to indicate the degree to which they have been bothered by that particular symptom over the past month. Scores range from 17 to 85, and can be categorized as *no symptoms,* 18-33 are categorized as *normal,* scores of 34-43 as *borderline* and 44-85 as *high.* Scores above 44 indicate that a participant may have PTSD or trauma-related problems and further investigation of trauma symptoms might be warranted.

In the present study, the internal consistency of the measure was α .90. PCL-M scores ranged from 17 to 46 with a mean of 25.40 (*SD* = 8.61). Two participants were classed as having a high level of PTSS; however, there was no significant difference between their scores and other informants that were classed as either borderline normal, or as having no symptoms (all *p's => .26*). Considering this result, we did not remove their responses from the analysis.

3.3.3 Procedure.

All service personnel were notified of the research being undertaken via a research poster in daily orders. Utilising deployment records, we identified personnel who had deployed on at least one operation in the last five years in a commander role, as they are required to report on personnel that served under their command during deployment. Thus, in these participants at least, rating other personnel is commonplace and thus less likely to be influenced by a lack of experience at the task. We invited individuals who met these criteria to attend a short briefing on the research and provided them with a research information sheet and consent form. We gave all personnel 24 hours to consider participating. The informing personnel responses were kept confidential.

3.3.4 Analysis.

We performed all analyses on Mplus version 7.0 (Muthén & Muthén, 1998-2015). Given the exploratory nature of the analysis and the relatively small size, we initially analysed the factorial validity of MRec and MRp as single factors using a BSEM in an exploratory manner. We initially attempted to analyse a two-factor model with all items. However, this analysis would not converge, thus we tested each factor separately in the first instance. The fourth stage of the study analyzed MRec and MRp as a two-factor model using BSEM.

3.4. Results

3.4.1 Stage 3: Single factor model testing strategy.

To assess the factorial validity of the MRec and MRp subscales, we completed single factor BSEM analyses. In line with guidelines (Muthén & Asparouhov, 2012) we analyzed two models for each subscale. The first model employed non-informative priors for the major loadings and exact zero residual correlations. The second model employed non-informative priors for the major loadings and informative priors for residual correlations. All data were standardized. All BSEM models were estimated with Markov Chain Monte Carlo (MCMC) simulation procedure with a Gibbs sampler and a fixed number of 100,000 iterations for two MCMC chains. This allowed for the examination of model convergence.

We assessed model convergence by the potential scale reduction (PSR) factor, where evidence for convergence is shown when the PSR value lies between 1.0 and 1.1 (Gelman, Carlin, Stern, & Rubin, 2004). We then assessed the model fit with posterior predictive checks. The checks indicate the degree of discrepancy between the model generated and observed data using the likelihood ratio χ^2 test and its posterior predictive *p* value (PPP). In a good fitting model, the PPP should be around .50 and a symmetric 95% confidence interval for the difference between observed and replicated χ^{2s} centred around zero (Muthén & Asparouchov, 2012).

3.4.2 Stage 3: MRec single factor analysis.

Adequate convergence was achieved for the MRec 13-item subscale with non-informative priors for the major loadings. However, the 95% posterior predictive confidence intervals did not encompass zero and the PPP for the model indicated a poor model fit (see *Table 3.1* for PPP and 95% confidence intervals). Item removal was based on a combination of factor loadings, standardized residuals and conceptual relevance. Low factor loadings demonstrate items that are poor indicators of the construct, while problematic residuals can mean that the model is either under or over parameterised. We also reviewed the missing data for each item and removed items with more missing data than responses as we considered them conceptually irrelevant (cf. Biddle, Markland, Gilbourne, Chatzisarantis, & Sparkes, 2001). Based on these criteria we removed six items (e.g. *"He feels he may have mistakenly caused the death of a child or other innocent person"*). This process of item removal left an MRec 7-item subscale.

Satisfactory convergence was achieved for the MRec 7-item subscale for both models. The first model with non-informative priors for the major loadings and exact zero cross-loadings did not encompass zero for the 95% posterior predictive confidence intervals and the PPP indicated a less than desirable fit to the data (see *Table 3.1* for PPP and 95% confidence intervals). The second model with non-informative priors for the major loadings and informative priors for residual correlations indicated a good fit (see *Table 3.1.* for model PPP and 95% confidence intervals). All standardized factor loadings exceeded 0.8, composite reliability was 0.95 and PSR values for the final items reached the 1.1 criteria after 3300 iterations with an end PSR value of 1.00. K-S tests for all parameters were non-significant (*p*

> .05). Visual inspection of the trace plots showed support for convergence (i.e., all plots showed a stable convergence across iterations for the two chains).

Table 3.1. Study 1 BSEM fit for MRec and MRp single factor analysis.

Model	PPP	Lower 2.5%	Upper 2.5%
MRec			
1. 13-Item Non-informative	.000	299.40	422.12
2. 7-Item Non-informative	.000	32.91	83.82
3. 7-Item Informative priors (cross-loadings)	.528	-24.27	22.49
MRp			
1. 10-Item Non-informative	.000	237.24	324.31
2. 7-Item Non-informative	.000	118.53	166.10
3. 7-Item Informative priors (cross-loadings)	.523	-24.45	22.34

Note: PPP = posterior predictive p value; PSR = potential scale reduction

3.4.3 Stage 3: MRp single factor analysis.

A satisfactory convergence was achieved for the MRp 10-item subscale with non-informative priors for the major loadings and exact zero cross-loadings. However, the 95% posterior predictive confidence intervals did not encompass zero and the PPP for the model indicated a poor model fit (see *Table 3.1* for PPP and 95% confidence intervals). The same combination of statistical and theoretical criteria was employed as in the MRec single factor analysis. This resulted in three items (e.g. *"His recent performance has been poor"*) being removed, thus leaving a 7-item MRp subscale.

Satisfactory convergence was achieved for the MRp 7-item subscale for both models. The first model employed non-informative priors for the major loadings and exact zero cross-loadings. The 95% posterior predictive confidence intervals did not encompass zero and the PPP for the model indicated a poor model fit (see *Table 3.1* for PPP and 95% confidence intervals). However, the second model with non-informative priors for the major loadings and informative priors for residual correlations did see the 95% posterior predictive confidence intervals centre around zero and the PPP of .523 indicated a good fit for the 7-items. All standardized factor loadings exceeded 0.8, composite reliability was 0.96 and PSR values for the final items reached the 1.1 criteria after 2400 iterations with an end PSR value of 1.00. K-S tests for all parameters were non-significant ($p > .05$). Visual inspection of the trace plots showed support for convergence (i.e., all plots showed a stable convergence across iterations for the two chains).

3.4.4 Stage 4: Two-factor model testing strategy.

To assess the factorial validity of MRec and MRp as a two-factor model we conducted a series of three BSEMs (Muthén & Asparouhov, 2012). First, we examined a model with non-informative priors for the major loadings, exact zero cross-loadings and exact zero residual correlations. The second model employed informative priors for the major loadings and informative approximate zero cross-loadings. The third model employed informative priors for the major loadings, informative approximate zero cross-loadings and residual correlations. The analysis specified small prior variances for cross-loadings and residual correlations at ±.01. The indicators and factor loadings were standardized which corresponds to factor loadings and residual correlations with a 95% limit of ±.20, thus representing substantively small cross-loadings and residual correlations (Muthén & Asparouchov, 2012). As with the single factor models, the two-factor analysis used MCMC with the Gibbs sampler and two chains with 50,000 followed by 100,000 iterations to check convergence and the stability of the estimates. We inspected the Kolomogorov-Smirnov (K-S) test to assess convergence as it indicates if there are any significant differences between the estimated parameter distributions across the two chains. Model convergence was assessed by the PSR and model fit with posterior predictive checks, the PPP and 95% confidence intervals as with the single-factor analyses. Trace plots for each parameter were visually inspected to assess the stability of the means and variances across the two chains. Finally, we also conducted a sensitivity analysis as the specification of different prior variances may influence the posterior predictive *p* value and increase the variability of the estimates (Muthén & Asparouhov, 2012). We tested this by specifying smaller (.005) and larger (.015) prior variances for the cross-loadings and the parameter estimates to assess stability and check for any important discrepancies by comparing them to the prior specifications.

3.4.5 Stage 4: Two-factor analysis.

The analysis of the two-factor 14-item MR-MO achieved adequate convergence for all three models. Firstly, with non-informative priors for the major loadings, the 95% posterior predictive confidence intervals did not encompass zero and the PPP for the model indicated a poor model fit (see *Table 3.3* for PPP and 95% confidence intervals). The second model with informative small variance priors on cross-loadings also failed to encompass zero for the 95% posterior predictive confidence intervals. The third model with informative priors on the cross-loadings and residual correlations did see the 95% posterior predictive confidence intervals centre around zero and the PPP of .558 indicated a good fit for the two-factor 14-item MR-MO. All standardized factor loadings exceeded 0.8, composite reliability was 0.97 and PSR values for the final items reached the 1.1 criteria after 4300 iterations with an end PSR value of 1.00. K-S tests for all parameters were non-significant (p > .05). Visual inspection of the trace plots showed support for convergence (i.e., all plots showed a stable convergence across iterations for the two chains). Sensitivity analysis indicated that the factor loadings and cross-loadings were relatively stable when specifying prior variances for cross-loadings at smaller (.005) and greater (.015 values) with no meaningful difference. Means, standard deviations and factor loadings with 95% credibility intervals for each item and the mean score and standard deviation for each subscale are displayed in *Table 3.2*. and BSEM results for fit and convergence are displayed in *Table 3.3*.

Table 3.2. Study 1 and 2 Standardized factor loadings with 95% credibility intervals, means and standard deviations for MR–MO.

"Based on my observations of Soldier 'X' while on an operational deployment, Soldier 'X' is able to maintain a high level of personal performance, even when:"	Study 1 (n = 195)		Study 2 (n = 137)	
	Loading (95% CIs)	M (*SD*)	Loading (95% CIs)	M (*SD*)
MRp				
1. He is suffering from fatigue (e.g. associated with high levels of mental effort).	0.85 (.65, 1.08)	5.30 (1.84)	0.62 (.25, .90)	4.10 (1.70)
2. He has not had much sleep.	0.93 (.72, 1.13)	5.47 (1.66)	0.71 (.35, 1.00)	4.19 (1.77)
3. The conditions are difficult (e.g., on patrol/ deliberate operations).	0.84 (.60, 1.05)	5.93 (1.56)	-	-
4. He is in pain (e.g., associated with high levels of physical effort).	0.92 (.72, 1.12)	5.46 (1.67)	0.75 (.42, 1.02)	3.77 (1.66)
5. He is under pressure to perform well (e.g., during a hostile contract).	0.85 (.65, 1.06)	5.78 (1.74)	0.70 (.23, .97)	4.62 (1.99)
6. It is an important section event.	0.91 (.67, 1.11)	5.99 (1.55)	-	-
7. Elements of the Indigenous Armed Forces have recently attacked British troops.	0.86 (.63, 1.08)	5.31 (1.88)	0.78 (.37, 1.03)	4.15 (1.98)
Total MRp		5.57 (2.13)		4.00 (1.43)

MRec				
1. It is unclear how and when he will return to a place of safety.	0.83 (.60, 1.04)	5.13 (2.13)	0.73 (.45, .97)	4.17 (1.78)
2. In a potentially traumatic event.	0.86 (.65, 1.09)	5.44 (1.66)	0.72 (.43, .98)	4.43 (1.81)
3. In the immediate aftermath of a potentially traumatic event.	0.91 (.69, 1.11)	5.41 (1.62)	0.62 (.29, .91)	4.73 (1.93)
4. Fellow team members have been WIA (suffering life changing injuries).	0.88 (.66, 1.09)	5.20 (2.05)	0.58 (.29, .85)	2.47 (1.93)
5. Required to revisit a location or undertake a task where traumatic events have previously occurred.	0.93 (.72, 1.15)	5.40 (1.74)	0.65 (.39, .89)	4.43 (1.81)
6. The job assigned to him is unpleasant (e.g., handling human remains).	0.80 (.57, 1.03)	5.39 (1.48)	0.85 (.61 1.06)	3.42 (1.57)
7. He has been unable to assist a wounded comrade.	0.83 (.48, 1.14)	4.68 (2.14)	0.88 (.67, 1.08)	3.60 (2.08)
Total MRec		5.41 (1.25)		3.89 (1.50)

Table 3.3. BSEM fit and convergence for two-factor models.

Model	Difference between observed and replicated χ^2 95% CI				
	No. free parameters	PPP	Lower 2.5%	Upper 2.5%	PSR
Study 1					
Non-informative	43	.000	272.25	367.85	1.00
Informative priors (cross-loadings)	57	.000	171.77	275.03	1.00
Informative priors (cross-loadings + residual correlations)	148	.588	-47.15	41.13	1.00
Study 2					
Non-informative	37	.000	141.23	214.29	1.00
Informative priors (cross-loadings)	49	.000	126.27	206.78	1.00
Informative priors (cross-loadings + residual correlations)	115	.529	-38.96	37.24	1.03

Note: PPP = Posterior Predictive p Value; PSR = Potential Scale Reduction

Although the BSEM analyses supported the two-factor structure of the MR-MO, the correlation between MRec and MRp was .93. Given the substantial size of this correlation, we reanalyzed the data as a "true" single factor model where all items were allowed to load on one factor to examine whether, from a measurement perspective, the MRp and MRec factors should actually be replaced by a generic robustness factor. Results indicate a marginally poorer model fit for the single-factor model, as the Deviance Information Criterion (DIC) was higher for the single factor model than the two-factor model (3927.44 vs. 3929.21). This result suggests that, based on parsimony, the two-factor model may be a better fit (Muthén & Asparouhov, 2012), although the differences in DIC are minor (we return to the issue of whether these factors are best treated as separate in the general discussion).

3.5. Discussion

Study 1 provided initial support for the two-factor 14-item MR-MO. Despite the promising model fit, it was important to confirm the factor structure on a separate sample. The first aim of Study 2 further examined the factor structure of the MR-MO with a separate sample of Army infantry personnel (INF) who complete dismounted ground close combat roles while on operations. In addition to confirming the factor structure of the MR-MO, our secondary aim of Study 2 was to provide initial support for the construct validity of the measure. More specifically, we compared differences in mental robustness scores between RMs and INF in Study 2. We specifically chose to compare these two services as while they both are 'infantry' forces, RMs are acknowledged as one of the world's elite commando force undergoing 32-weeks of basic training; in comparison INF receive less than half that undergoing a 14-week basic training course thus differences between these two services may be expected in relation to mental robustness.

The successful completion of rigorous military selection and grueling training, such as that completed by RMs, has been identified as an indicator of psychological hardiness associated with stress tolerance (Bartone, Roland, Picano, & Williams, 2008) and behavioral persistence (Le Bue, Kintaert, Taverniers, Mylle, Delahaij, & Euwema, 2016). Selection and training have also been identified as a protective factor, reducing the psychological impact of deployment experiences (Iversen, Fear, Ehlers, Hacker-Hughes, Hull et al., 2008). With these issues in mind, we expected to see higher informant ratings of MRp and MRec for RMs than Army personnel.

Previous research has indicated a number of factors (e.g., educational attainment and combat exposure) in addition to military selection and training that influence the effect of operational deployments on troops. Educational attainment has been identified as a protective factor in relation to soldier mental health, with individuals with a higher level of education at lower risk of screening positive for PTSD (Booth-Kewley, Larson, Highfill-McRoy, Garland, & Gaskin, 2010). In contrast, combat exposure has been identified as a health risk factor with personnel employed in ground close combat roles at highest risk of experiencing negative health consequences (e.g., memory distortion) associated with combat operations (Sundin et al., 2010; Iversen et al., 2008). As such the experience and impact of operational deployment is not universal across occupational groups (Sundin, Jones, Greenberg, Rona, Hotopf, Wessley, & Fear, 2010). Considering this, we examined group differences in levels of informant-rated mental robustness controlling for informant's educational attainment and combat exposure.

Study 2

3.6 Method

3.6.1 Participants.

One hundred and forty-one male Army personnel were reported on by 26 senior male non-commissioned officers (NCO). The NCOs were aged between 22 and 37 *(*M_{age} = 30.71, *SD* = 3.83) and had served in the Army for between 5 and 19 years (M = 12.25, *SD* = 3.57). All informants had deployed on operations with at least one operational deployment in the past five years (*M* = 1.83, *SD* = .56) in ground close combat roles. Service ranks ranged from Lance Corporal (OR-3) to Warrant Officer Class II (OR-8). Informant's reported educational attainment ranged from no formal qualifications to GCE Advanced Level, with 50 percent of informants attaining GCSE level. Data from four personnel were removed due to incomplete questionnaires leaving data on 137 personnel subject for analysis. Informants reported on between 3 and 12 (M = 6.38, *SD* = 3.69) Army personnel each.

3.6.2 Instruments.

Mental Robustness. We used the 14-item MR-MO developed in Study 1.

Post-Traumatic Stress. We again used the 17-item PCL-M (α .88) to screen for PTSS. Although in the previous study PTSS did not impact the reliability of the MR-MO responses we continued to screen for PTSD. PCL-M scores ranged from 17 to 52 with a mean of 29.41 (*SD* = 9.59) categorized as normal. Two participants were classed as having a high level of PTSS; however, there was no significant difference between their scores and those of other informants that were classed as either borderline normal, or as having no symptoms (all *p's* > *.53*). Considering this, we did not remove their responses from the analysis.

3.6.3 Procedure.

We used the same procedure in Study 2 that we used in Study 1.

3.7. Results

3.7.1 Stage 5: Two-factor model testing strategy.

The factorial validity of MRec and MRp as a two-factor model was assessed via a series of three BSEMs (Muthén & Asparouhov, 2012) as conducted in Study 1.

3.7.2 Stage 5: Two-factor analysis.

The analysis of the two-factor 14-item MR-MO achieved adequate convergence for all three models. Firstly, with non-informative priors for the major loadings, the 95% posterior predictive confidence intervals did not encompass zero and the PPP for the model indicated a poor model fit. The second model with informative small variance priors on cross-loadings also failed to encompass zero for the 95% posterior predictive confidence intervals. The third model with informative priors on cross-loadings and residual correlations did see the 95% posterior predictive confidence intervals centre around zero and the PPP of .558 indicated an excellent fit for the two-factor 14-item MR-MO. However, the MRp item *"It is an important section event"* had a standardized factor loading of .30 and MRp item *"The conditions are difficult (e.g., on patrol/ deliberate operations)"* wanted to significantly cross-load beyond its priori limit. The PSR values for the final model did not reach the 1.1 and K-S tests revealed a number of parameters associated with these items to be significant. A visual inspection of trace plots for the problematic parameters showed a number of upward or downward trends in the means with the two chains failing to overlap in their variability. As a result, these two identified problematic items were removed resulting in a 12-item (5-MRp, 7-MRec) MR-MO.

We performed the same analyses on the two-factor 12-item MR-MO. The measure achieved adequate convergence for all three models. Firstly, with non-informative priors for the major loadings the 95% posterior predictive confidence intervals did not encompass zero and the PPP for the model indicated a poor model fit (see *Table 3.3* for PPP and 95%

confidence intervals). The second model with informative small variance priors on cross-loadings also failed to encompass zero for the 95% posterior predictive confidence intervals. The third model with informative priors on cross-loadings and residual correlations did see the 95% posterior predictive confidence intervals centre around zero and the PPP of .529 indicated an excellent fit for the two-factor 12-item MR-MO. The model demonstrated a good fit, with standardized factor loadings exceeding 0.6 for all items in the model and composite reliability was 0.90. PSR values for the final items reached the 1.1 criteria after 2000 iterations with an end PSR value of 1.00. Sensitivity analysis indicated that the factor loadings and cross-loadings were relatively stable when specifying prior variances for cross-loadings at smaller (.005) and greater (.015 values) with no meaningful difference. Means, standard deviations and factor loadings with 95% credibility intervals for each item and the mean score and standard deviation for each subscale are displayed in *Table 3.2.* and BSEM results for fit and convergence are displayed in *Table 3.3*[1].

As in Study 1, the BSEM analyses supported the two-factor structure of the MR-MO, the correlation between MRp and MRec factors was .82. Given the substantial size of this correlation, we reanalyzed the data as a "true" single factor model as done in Study 1. Results indicate a marginally poorer model fit with the DIC higher for the single factor model than the two-factor model (3688.92 vs. 3683.75), suggesting that, based on parsimony, the two-factor model is a marginally better fit. The final copy of the questionnaire is provided in Appendix B.

3.7.3 Stage 6: Construct validity.

A secondary focus of the current study was to examine the construct validity of the MR-MO. We have already shown that PTSS does not impact how informants rate mental

[1] For the sake of completeness, we analysed the two-factor 12-item MR-MO with the data collected from the RMs, improved convergence for all three models was achieved.

robustness. We next examined if factors that have been identified as impacting mental robustness either positively (e.g. rigorous selection, training, educational attainment) or negatively (e.g. combat exposure) influence how informants rate mental robustness.

The mean score for the 193 RMs rated in Study 1 for the 7-MRec items was 5.41 (SD = 1.25) and for the 5-MRp was 5.57 (SD = 2.13). We conducted a multivariate analysis of covariance on the MRec and MRp data with informant educational attainment (considered a protective factor) and informant combat exposure (considered a risk factor) included as covariates to examine if the RMs and INF differed in the MRec and MRp whilst controlling for these covariates. Firstly, we examined the influence of the covariates. For MRec, education (F (1,326) = .23, p = .63, partial η^2 = .001) did not have a significant impact on informant's ratings. However, combat exposure, did have a significant effect on informant's ratings (F (1,326) = 36.60, p =.001, partial η^2 = .101). For MRp, the opposite was found; education had a significant impact on ratings of MRp (F (1,326) = 13.36, p = .001, partial η^2 = .039) while combat exposure (F (1,326) = 1.59, p = .20, partial η^2 = .005) did not have a significant effect on informant ratings. Despite the influence of these covariates, the MR-MO was still able to discriminate between the two service groups with results revealing a significant effect of service on the combined dependent variable of mental robustness (F (1,326) = 20.86, p = .001, partial η^2 = .114; Pillai's trace = .114). Univariate analysis on both dependent variables showed a significant difference between service groups with RMs scoring personnel higher on MRp (F (1,326) = 16.94, p = .001) and MRec (F (1,326) = 28.86, p = .001).

3.8. General Discussion

The purpose of the present research was to develop and validate a two dimensional measure of mental robustness that was relevant for a military operational enviroment. Study 1 found good support for the structural validity of the MR-MO, while Study 2 confirmed the structural validity of the two-subscale 12-item MR-MO and provided some evidence of the measures construct validity by demonstrating differences between RMCs and Army personnel on MRp and MRec whilst controlling for informant educational attainment and combat exposure.

While previous research has examined mental robustness as a one-dimensional trait (e.g. Arthur et al., 2015) this is the first-time mental robustness has been examined as a multidimensional measure relevant to military operational contexts. However, the high correlations between the factors may lead one to argue that, from a measurement perspective at least, the two subscales in the MR-MO are measuring the same thing. Conceptually, these items are measuring different aspects of mental robustness in relation to operational deployment. More specifically, as we noted in the introduction, MRp focuses on one's ability to maintain performance in the face of trauma when one is the agent of events, and MRec considers the ability to maintain performance in difficult situations when one is the subject of events. The high correlation may simply be an artefact of measurement. In other domains of psychology, such as in Self-Determination Theory, measures of some factors have high intercorrelations (Niven & Markland, 2016). For instance, the three basic needs are highly correlated in measurement terms but are still considered as separate things. Given their difference in focus it is likely that MRp and MRec will predict divergent outcomes (e.g., performance vs health). Evidence of this nature will help to provide more support for the two-factor model we propose here. Work is required to fully consider whether these two factors are in fact separate dimensions of MR or if there is instead a causal relationship between the factors in which a third factor influences MRp and/ or MRec.

In addition, to the high correlation between the factors, a number of methodological and measurement issues are worthy of note. The use of informant ratings of mental robustness can be seen as a strength of the study, as we were able to circumvent some of the social desirability issues associated with self-reporting mental robustness (see Hardy et al., 2014). It should also be noted that many of these measures are self-report. It has been argued that the use of self-report measures would not necessarily provide reliable data considering the social desirability and self-presentation confounds associated with mental toughness (Hardy, et al., 2013). However, this approach does not avoid issues relating to use of single-source data that has plagued most of the existing mental toughness literature. While it was not possible within this study due to availability of personnel, a triangulation approach across different assessors for the same individual would resolve this issue. Within a military setting this triangulation approach could be achieved by Section Commanders, Officer Commanding and peers taking on the role as assessors. The use of multiple informant assessments would also allow researchers to assess for inter-rater consistency (Gucciardi, Jackson, Hanton & Reid, 2015) and are also less likely to be confounded by other informant variables such as skill, talent and practice (Hardy, et al., 2013). Considering this, future research employing the MR-MO should look to establish inter-rater reliability using a triangulation approach to data collection.

The BSEM approach used here allows for a more appropriate approach to model testing, that allows one to be theoretically focused yet not overly restrictive in terms of model specification. To the best of our knowledge, this is the first time that the BSEM approach has been used with military samples, and we hope that this paper helps to ignite more enthusiasm for this analytical approach within the military. However, an important point to note is that the analyses reported here do not take into account the multi-level nature of the data. Currently, the model fit statistics used by MPlus for Bayesian SEM are not available for multilevel models. Thus, we were unable to fully examine the factorial validity and theoretical grounding of the MR-MO as a multi-dimensional measure at this time. With advances in programming capabilities assessing the multidimensional nature of the measure will be important.

War is a stressful business and military personnel must be inherently capable and properly prepared. Personnels' experiences of combat are individualised, and their reaction is one to an abnormal situation. While previous research (e.g., Sundin et al., 2010) indicates that a high level of preparedness may lessen the psychological impact of operational deployments, preparing for the emotional challenges war presents is inherently difficult to do. While some effort has been made in recent years utilizing amputee actors during pre-deployment training the vast majority of training still focuses on the MRp aspect of mental robustness with far less time devoted to preparing personnel for the emotional challenges of war. A better understanding of mental robustness may, therefore, aid in the development of effective selection and intervention tools that taps not only MRp but also MRec which may, in turn, see a reduction in some of the negative mental health consequences associated with combat exposure.

Combat operations require personnel to make split-second decisions that could result in loss of life while performing effectively in the short term during operational deployment is incredibly important. A crucial issue that needs to be considered is military personnel’s ability to perform effectively during combat operations without incurring a long-term mental health cost. Mental robustness is particularly relevant in predicting individuals’ ability to resolve a conflicting response thus allowing them to effectively perform a task. Understanding the cognitive and behavioural processes employed in response to threat by military personnel while on operations may help predict rates of mental robustness. Such an approach, if combined with fMRI, would also allow researchers to understand which neural networks are associated with MRp and if they differ to the networks associated with MRec. Obtaining evidence for differences in the neural networks for MRp and MRec would provide more evidence that these two factors of mental robustness are different and worth treating separately. Considering this, future research could provide an insight into mission ready personnel's enhanced ability to anticipate and conceive possible responses to presented combat situations and the impact this may have on the prevalence of PTSS.

In a contemporary military where amalgamation and downsizing are prevalent, priority should be given to equipping, training and educating personnel to a high standard to create a robust effective force. The current research is an important step in the development and validation of the first two-dimensional informant-rated measure of mental robustness relevant to a 21st-century military operational environment. We hope that this research will stimulate further theoretical and applied research in this area.

Chapter 4

Functional Magnetic Resonance Imaging (fMRI)

4.1. Introduction

The past two decades have seen huge advances in the ability to visualise and measure aspects of the human brain. As the techniques have become more accessible and affordable its application has diversified and it is now used in areas of research not traditionally linked to neuroscience. Neuroimaging provides a set of tools that can address a wide variety of questions by providing an opportunity to indirectly observe neural activity noninvasively in the human brain as it changes in near real time.

4.1.1. A brief history.

The foundations of MRI stem back to the work of Austrian physicist Wolfgang Pauli in the 1920s who noted some anomalies in the electromagnetic spectra emitted by excited atoms. However, his theory was not tested for over a decade and resulted in the discovery of magnetic resonance by American physicist Isidor Rabi (see *4.3. Basic physics underpinning MRI* for more detail). By the 1970's MRI was a well-established tool of chemists. This led to the study of intact biological systems leading to the emergence of transformative technologies in MRI by Raymond Damadian, a medical doctor and research scientist. Damadian discovered that magnetic resonance imaging could be used as a tool for medical diagnosis as different kinds of animal tissue emit response signals that vary in length (Damadian, et al., 1973).

Inspired by Damadian's findings, American physicist Paul Lauterbur introduced spatial gradients in the magnetic field. By acquiring four gradients in succession Lauterbur was able to create the first magnetic resonance image (Lauterbur, 1973). Although revolutionary Lauterbur's method was inefficient as there was a considerable redundancy in the data collected and the approach was time-consuming. A more efficient technique was proposed by the British physicist Peter Mansfield, known now as echo-planar imaging (EPI; Mansfield, 1977). This approach allowed the collection of data from an entire image slice at one time. This was done by sending one electromagnetic pulse from a transmitter coil before introducing rapidly changing magnetic field gradients while recording the MR signal (Song, Huettel, & McCarthy, 2006). Concepts derived from EPI underlie the most important approaches to MRI or at least functional MRI (fMRI) today. As a result, Lauterbur and Mansfield were jointly awarded the Nobel Prize in Physiology and Medicine in 2003. While the theoretical underpinnings of MRI at this point in time were in place, there were still substantial engineering issues yet to be solved. This was soon resolved in 1977, by Damadian and his lab staff who hand build the first MRI scanner, dubbed the *"Indomitable"* (c.f. Kleinfield, 2014). The first commercial high-field (1.5-Tesla[1]) MRI scanner was created by General Electric in 1982. Two years later, 1.5-T MRI scanners came into common clinical use (Luecken & Gallo, 2008). Although much knowledge about the brain stems from structural images, notably by relating neurological disorders to the patterns of brain injury that cause them, they cannot reveal short-term physiological changes associated with the activation of the brain. In 1990, Ogawa, and colleagues demonstrated that the appearance of the brain's blood vessels changed with blood oxygenation. This technique has come to be known under the acronym BOLD (blood-oxygenation-level-dependent; see section *4.4. Physiology underpinning functional imaging* for a more detailed explanation). The discovery that blood oxygenation could be measured by MRI ushered in a new era of functional studies

[1] Tesla (T) is the unit of measurement quantifying the strength of a magnetic field, named after Nikola Tesla who discovered the rotating magnetic field in 1882.

of the brain. The technique as a whole has had enormous influence and has generated more than one Nobel prize.

4.2. Brain Anatomy

Neurons are organised within the brain to form grey matter and white matter. Grey matter contains most of the neurone cell bodies and unmyelinated axons, it serves to process information in the brain. The grey matter is a highly convoluted sheet (the cerebral cortex, approximately 3mm thick) on the surface of the cerebrum, beneath which lies the white matter. It is the white matter that transmits information to the grey matter and is mainly compromised of long-range myelinated axons (which makes white matter appear white) and a small amount of neuronal cell bodies. In the center of the brain, beneath the bulk of the white matter fibers, there is another collection of grey matter structures which includes the basal ganglia, the limbic system and the diencephalon (Ward, 2015).

Grey and white matter are relatively evenly split each comprising approximately 50 percent of the human brain (Harris & Attwell, 2012). Traditionally fMRI has been used to study grey matter, however, a growing body of work supports the notion that fMRI can be used to study functional dynamics in white matter (Gawryluk, Mazerolle, & D'Arcy, 2014).

4.2.1. Functional organisation of the brain.

Functional brain imaging gives us increasingly detailed information about the location of brain activity. One of the most influential ways of dividing up the cerebral cortex is in terms of Brodmann's areas (Brodmann, 1909), who divided the cortex up into 52 areas, many of which have since been subdivided. These areas were defined solely by their cytoarchitecture[2]. Though there is an ongoing debate about the definition and border of regions some researchers have in recent years identified brain regions that respond selectively

[2] Cytoarchitecture is the differences in the size, types and distribution of neurons within a brain region.

to single categories of visually presented objects (e.g. extrastriate body area (EBA), Downing, Jiang, Shuman, & Kanwisher, 2001).

Advances in imaging techniques have allowed for a more refined description of the organisation of the brain with many of Brodmann areas now correlated to various cognitive functions. For example, the Extrastriate Body Area, which is involved in the visual perception of the human body and body parts, is located in Brodmann Area 37. As cognitive functions become more complex the functional specialisation of the region becomes more blurred. Memories are a good example of this as they can be extremely rich in detail and can include sensory material, feelings, words and much more. As such, memory is not located in just one brain region and is instead distributed throughout a vast area of the brain depending on the type of information to be maintained (Eriksson, Vogal, Lansner, Bergstöm & Nyberg, 2015).

Even with perfect anatomical mapping, there are still issues relating to anatomical regions and functional divisions within the brain. Although the spatial resolution is typically good enough to localize brain activity at the level of major, because of its poor temporal resolution fMRI is not appropriate for resolving small timing differences between different cognitive stages or processes (Dobbs, 2006).

4.3. Basic Physics Underpinning MRI

MRI is based on a physics phenomenon discovered in the 1930s, called nuclear magnetic resonance (NMR; Rabi, Zacharias, Millman & Kusch, 1938). NMR is a phenomenon which occurs when the nuclei of hydrogen atoms are immersed in a static magnetic field and exposed to a second oscillating magnetic field (Lauterbur, 1973). Briefly, the nucleus of an atom is composed of protons and neutrons, both of which have a distribution of electric charge. The distribution of charge in the nucleus spins about randomly, this spinning is the equivalent of an electric current. When placed in a magnetic field it partially polarizes the nuclear spin and a small fraction of them will align themselves known as a ‘nuclear magnetic moment’ (Pykett, et al., 1982). When protons are in the aligned state a brief radiofrequency (RF) pulse is applied which knocks the orientation of the aligned protons by 90 degrees to their original orientation. As the proton's spin in this new state, they emit a detectable NMR signal. It is the concentration of the proton NMR that forms the basis of the MR signal (James, 1998). The protons will then “relax” and return to their original alignment. The scanner repeats this process serially with slices collected most commonly on an interleaved basis; with the advent of acquisition methods such as EPI, a whole brain can be scanned in two seconds with slices of three millimetres (Feinberg, et al., 2010).

The rate in which the proton relaxes and returns back to the aligned state enables researchers to distinguish between different types of tissue. There are two types of relaxation commonly measured by MRI: (1) T1 or longitudinal relaxation - a measure of the time taken for protons to realign with the external magnetic field. (2) T2 or transverse relaxation – a measure of the time taken for protons to return to transverse equilibrium. The T1 is typically used to produce detailed structural images of the brain, to create a T1 image the repetition time (TR) of the RF pulse needs to be short, typically 500 milliseconds. The T2 is typically used when researchers want to collect functional images of the brain, these are created by using longer TR times, typically 2000-4000 milliseconds (McRobbie, Moore, & Graves, 2017). In general, T1 and T2 weighted images can be easily differentiated as the cranial spinal fluid (CSF) is dark in T1 weighted images and brighter in T2 weighted images (see *Figure 4.2*.)

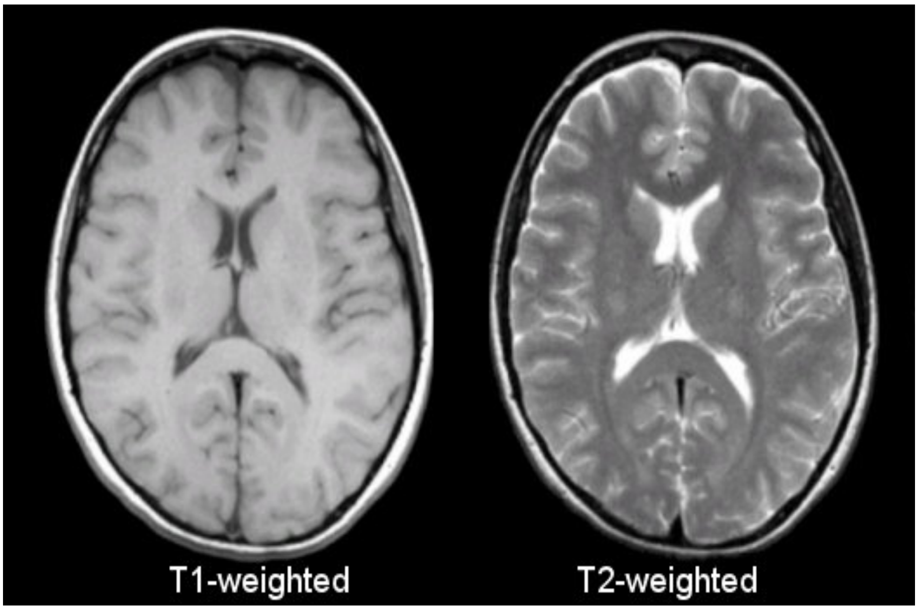


Figure 4.1. T1-weighted images show fat and white matter in light, while the CSF and the cortex appear dark. In T2-weighted images, the CSF and the fat are light while white matter and the cortex appear dark.

4.4. Physiology Underpinning Functional Imaging

The brain consumes 20 percent of the body's oxygen uptake; with the brain's oxygen and energy needs are supplied by the blood. When the metabolic activity of neurons increases, the blood supply to that region increases to meet the demand (Raichle, 1987). When neurons are activated they consume oxygen, this initially results in a dip in oxyhemoglobin. In response, the blood flow and volume to the region are increased producing a peak (Malonek, et al., 1997; see *Figure 4.3*). Finally, the blood flow and oxygen consumption dip (or undershoot) before returning to normal. The MR signal is sensitive to the amount of deoxyhemoglobin in the blood as it has strong paramagnetic properties (Ogawa, et al., 1990). The presence of paramagnetic molecules in blood produces a difference in magnetic susceptibility between the blood vessel and the surrounding tissue (Ogawa, et al., 1990). This distortion can itself be measured to give an indication of the deoxyhemoglobin present in blood, producing blood oxygenation level-dependent (BOLD) contrast (Ogawa, et al., 1990). Information provided by the BOLD signal is then used to make conclusions about the underlying unobserved neuronal activation (Ashby, 2015). The way the BOLD signal evolves over time (via an initial dip, an over compensation and finally an undershoot) is called the hemodynamic response function (HRF) which plays an important role in the analysis of fMRI data (Huettel, et al., 2004).

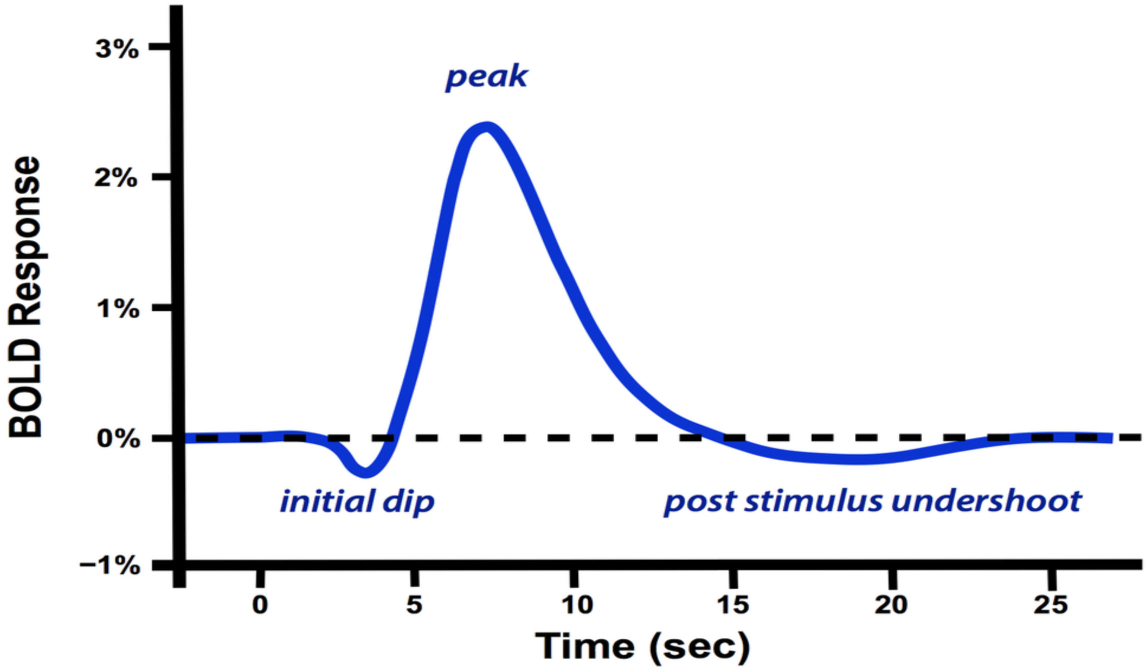


Figure 4.2. BOLD HRF following a single brief stimulus.

However, the BOLD response measured in most fMRI research provides only an indirect measure of neural activity and BOLD signal lags considerably behind the peak neural activation (Ogawa, et al., 1990). The BOLD response is therefore more closely related to local field potentials than to the spiking output of individual neurons (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001).

4.5. Experimental Design

4.5.1. Block design.

The block design is the traditional way of designing an fMRI experiment. It consists of a series of stimulus blocks (lasting from ~10 seconds to a couple of minutes) of the same condition, sometimes with a period of rest between each condition (See (a) of *Figure 4.4*). Originally, fMRI experiments utilised block designs in order to accumulate enough data to make a statistical analysis feasible (Toga & Mazziotta, 2002). Block designs are powerful for locating voxels in which the level of activity is significantly different in the task versus the control conditions. Consider the HRF described above, in a block design there is constant stimulation for the same condition for the duration of the trial, meaning that the HRF does not return to baseline during the trial. Because the same condition stimulus is presented repeatedly throughout the block the HRF in the active voxels accumulates, rising to a plateau rather than a short-lived peak (Ashby, 2015). HRF decay back to baseline therefore only occurs during the rest periods. Although block designs are better at detecting significant but small effects (Josephs & Henson, 1999), they are not suitable for all experimental designs as they require a large number of replications.

4.5.2. Event-related design.

The event-related design moves away from blocking the experimental conditions. Instead, they are run as a set of discrete trials with condition stimulus often repeated randomly over the course of the experiment (See (b) of *Figure 4.4*). An event-related design allows researchers to learn about the HRF or BOLD response (the time course of activity) to a single event/trial. This not possible with a block design as it averages out the HRF, thus blurring individual responses (Penny, et al., 2011).

Event-related designs stimuli can be presented rapidly, the use of 'null-events'[3], allows for the estimation of the HRF to a particular stimulus. This is done by subtracting the event-related average of the null-event trails from the average of the event types of interest (Friston, Zarahn, Josephs, Henson, & Dale, 1999). In addition to null-events, it is recommended that researchers place a delay between trials (typically 16 seconds; Penny, et al., 2011). This allows researchers to measure "true" HRF to each event. It will also allow the stimulus presentation to synchronise with the TR. However, these long delays aren't necessary if conditions are counterbalanced as the effects of the preceding trials all wash out. A big advantage of counterbalancing is that researchers can fit in more trials per minute which will result in greater power.

Event related designs have expanded the flexibility of fMRI experimental design. For instance, groupings can be determined post-hoc by the participant's responses, or if the task requires the stimulus condition to be unexpected, such as during a threat detection task. In a task such as this, the element of surprise is essential to gain meaningful results. Finally, event-related designs are more efficient estimators than block designs as the BOLD signal is allowed to overlap between conditions (Dale, 1999).

4.5.3. Free viewing.

The vast majority of fMRI studies utilise explicit evaluative behavioural tasks, which are often repetitive in nature using either a block design or an event-related design. However, these methods in isolation fail to harness the attributes of naturalistic environments. While easier to implement the conventional methods lack correspondence to the real world, which is rarely organised in an orderly manner (Hasson, Nir, Levy, Fuhrmann, & Malach, 2004).

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[3] Null-events are defined periods of time in the stimulus sequence that contains a fixed condition such as a small fixation cross (Buckner, et al., 1998).

The human brain functions in an extremely stimulating world continuously exposed to a stream of multisensory, audio and visual stimulation. Reproducing this in an MRI environment is inherently difficult. To overcome the limitation of typical visual mapping experiments that rely on predetermined stimulation protocols Hasson, et al., (2004) proposed a more naturalistic *'free-viewing'* approach (See (c) of *Figure 4.4*). In this approach, stimuli are embedded in complex multi-object scenes moving in a complex manner within the stimulus, such as movies (Hasson, et al., 2004; Jaaskelainen, et al., 2008; Kauppi, et al., 2010). Movie viewing provides rich and complex stimulation much closer to ecological vision than in conventional, strictly controlled research paradigms. The use of naturalistic stimuli (such as movie footage) offers the possibility of understanding higher-order brain functions (Kauppi, et al., 2014). However, this increase in ecological validity leads to a reduced control over possible confounding variables.

Much of the research conducted thus far has utilised the use of free-viewing stimuli using movies (e.g. Hasson, et al., 2004; Kauppi, et al., 2010; Nummenmaa, et al., 2012). However, the use of movies has been criticised for being unnatural stimulus, as they are edited using multiple scenes and camera angles to draw the viewer in and promote the desired narrative, thus maximising the viewer's attention (Jola, et al., 2013). First person, continuous, unedited stimulus is recommended to deliver the most natural visual experience (Jola, et al., 2014).

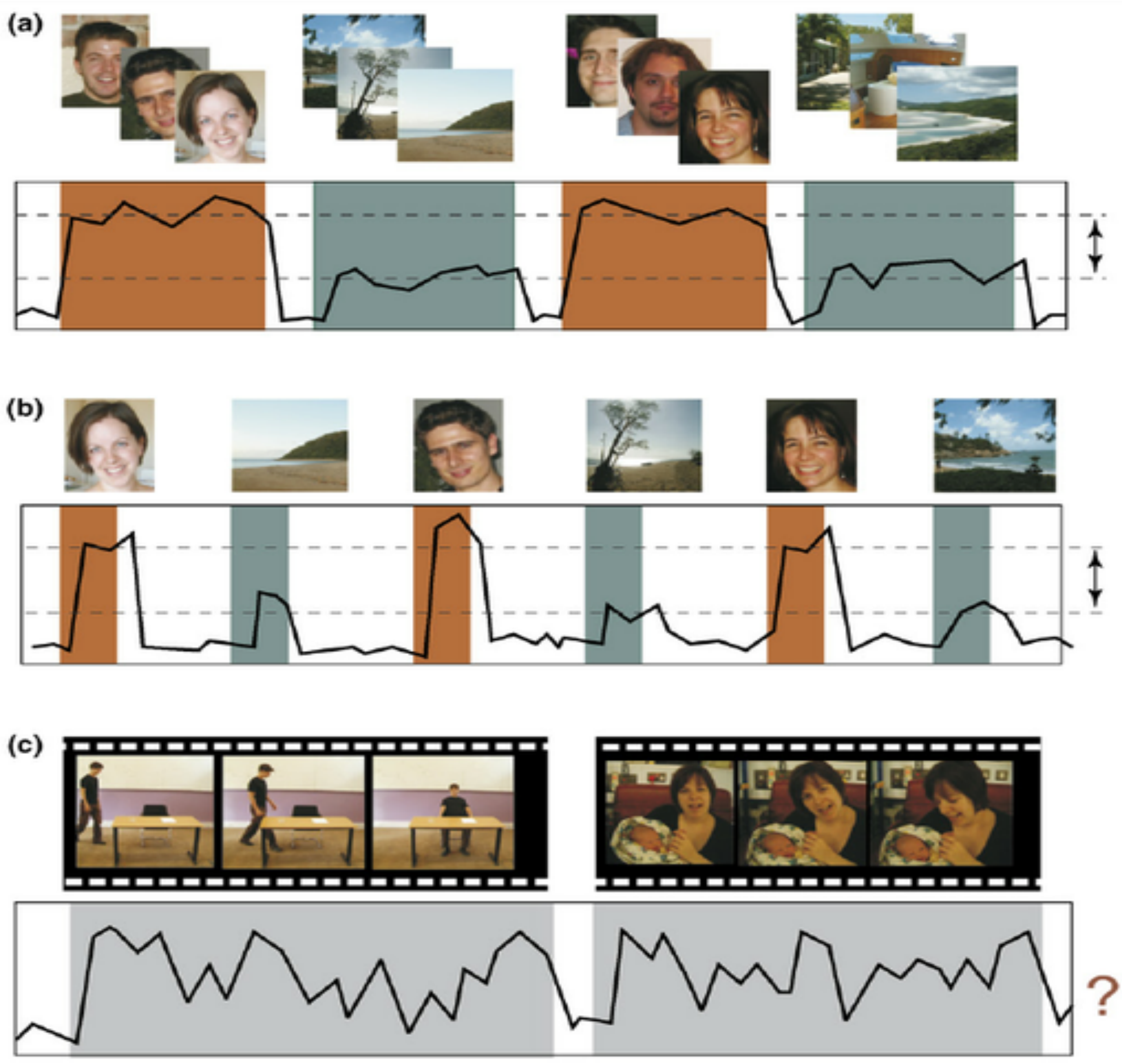

Figure 4.3. Example stimuli are shown above the illustrative activity time course of a single voxel. Traditional fMRI experimental designs consist of either (a) a block design or (b) an event-related design. A comparison is made between the amount of activity evoked by viewing faces relative to the amount evoked by viewing scenes (dashed lines). The voxel measured shows a preference for faces over scenes. In block designs, activity is averaged over the duration of each block. (c) An example of an experiment involving movies of dynamic naturalistic stimuli. In this case, averaging the activity over the block ignores the complexity of the stimuli, also there are no pre-defined discrete events to conduct a standard event-related analysis and so a novel means of analysis must be used (Spiers & Maguire, 2007).

4.5.4. Resting state.

Resting state functional MRI (RS-fMRI) evaluates regional interactions that occur when a participant is not performing an explicit task (Uddin & Menon, 2010). The discovery of coherent spontaneous fluctuations within the somatomotor system was first presented by Biswal, Zerrin Yetkin, Haughton, and Hyde, (1995). Building on Biswal's work a number of studies have shown that many of the brain areas engaged during various cognitive tasks also form coherent large-scale brain networks that can be identified using RS-fMRI (Smith, et al., 2009). Today it is now considered one of the leading approach to the study of brain organization (Power, Schlaggar, & Petersen, 2014).

Here participants not presented with any stimulus are asked to keep their eyes open, close their eyes, or focus on a fixation (Patriat, et al., 2013). RS-fMRI measures spontaneous low-frequency fluctuations (<0.1 Hz) in the BOLD signal to investigate the functional architecture of the brain (Lee, Smyser, & Shimony, 2013).

RS-fMRI has been described as the workhorse of individual differences research as it is easy to perform and aggregate across subject populations and sites (Dubois & Adolphs, 2016). The low cognitive demand and relatively short duration of RS-fMRI scans make them well suited for scanning individuals with a low tolerance for the confined and noisy MRI environments, such as children and clinical populations (Uddin, Supekar, & Menon, 2010). As such, it has revealed important clinical applications in premature infants (Damaraju, et al., 2010) to active military personnel with traumatic brain injury (TBI; Han, et al., 2014) and PTSD (Dunkley, et al., 2014).

4.6. Pre-Processing MRI Data

There are a number of steps that need to be completed to prepare MRI data for task-related analysis. Typically, the same five pre-processing steps are always completed regardless of experimental design.

(1) *Slice-time correction* is most commonly the first pre-processing step, it corrects for the time between the acquisition of the first and last slice. It does this by ‘shifting’ slices in time to match a reference point.

(2) *Motion correction* is arguably the most important pre-processing step as even the smallest of imperceptible head movements can badly corrupt fMRI data. When a participant moves their head brain regions will move to different spatial locations. As a result, activation in those regions will be recorded in different voxels than they were before the movement occurred. Motion correction functions use BOLD responses from one TR as a standard, it then corrects every other TR until each of these data sets agrees as closely as possible with the standard.

(3) *Co-registration* is a step towards normalising the images. It aligns the structural and functional data into a common template space, as the structural are higher resolution this improves the spatial resolution of the functional data.

(4) *Normalisation* warps the participant’s structural image to a standardised brain atlas (e.g. Montreal Neurological Institute (MNI) atlas; Evans, Collins, & Milner, 1992). Because of the individual structural differences in brains, it is difficult to assign a task-related activation in a cluster of voxels to a specific neuroanatomical brain structure in a group level analysis. Researchers, therefore, register the structural scan of each participant to a standardised brain where all the major brain structures have been identified. This allows researchers to generalise across the sample of participants.

(5) *Spatial smoothing* is essential an averaging operation to reduce noise and increase the signal-to-noise ratio. The BOLD value in each voxel is replaced by a weighted average of the BOLD responses in neighbouring voxels. The weight is greatest at the voxel being smoothed and decreases with distance.

4.7. Task Related Data Analysis

Many techniques have been proposed for the statistical analysis of fMRI data, a variety of these are in general use. Their aim is to produce an image identifying the regions which show significant signal change in response to the task. This can then be used to produce a statistical parametric map or determine the height of the HRF in each of the conditions being tested. These maps describe brain activation by colour-coding voxels that exceed the statistical threshold for significance (Lindquist, 2008).

4.7.1 Cognitive subtraction.

One of the simplest analysis methods is to perform a subtraction. This is done by averaging out the activation for a condition and subtracting it from either the null events or from the other condition (Faro & Mohamed, 2010). The remaining activation can then be attributed as unique to the condition. However, caution should be taken as any/all differences between the conditions could be the source of the results. It is rare to have two conditions that only differ in one respect.

4.7.2 Regions of interest (ROI).

For simple comparisons creating a thresholded statistical map, showing which regions are activated above a defined threshold can be sufficient. However, there are often reasons to look further into particular ROIs. In complex designs, such as factorial designs with multiple levels, it can often be difficult to discern the pattern of activity across conditions from an overall map. This is because it is hard to distinguish contributions and sequential patterns can be difficult to identify. It can also allow researchers to control for Type I errors by limiting the number of statistical tests to a few ROIs. ROIs can be defined in a number of ways:

(1) *Atlas defined ROIs* allows researchers to use well established probabilistic atlases to identify ROIs. This atlas can be used as a mask over brain activation maps to identify ROIs or to possibly draw an ROI on the MNI template brain. These

atlases also provide coordinates for well-established brain areas which can be used to identify ROIs.

As it uses probabilistic atlas system descriptions based on hundreds of brain images of anatomical features findings using this method are comparable across subjects. However, this means that individual anatomical differences and functional variability are thus ignored.

(2) *Localiser defined* ROIs use separate localiser scans to identify voxels in a particular anatomical region that show a particular response (e.g. voxels in the extrastriate body area are more responsive to the human body and body parts and insensitive to faces and stimulus categories unrelated to the human body). These voxels are then explored to examine their response to some other manipulation.

(3) *Individually defined ROIs* see researcher's select functionally-activated voxels from each individual's results – either form a localiser task or a study task.

(4) *Group defined ROIs* see researcher's select functionally activated voxels from group results, then using that set of voxels as an ROI to extract from individuals. This method can be considered more reliable than the individually defining method as voxels that are above the activation threshold at a group level must be activated in most if not all participants. However, with that in mind the method doesn't account for individual variability which can be considerable (Poldark, 2007).

The data from ROIs can be extracted by *parameter estimate extraction,* this looks at the amount that the HRF needs to be scaled by to best fit the data at a given voxel. This can be useful for understanding contrasts that include a number of conditions (assuming that each condition is modelled separately). However, it does not provide much new information other than collapsing across voxels within the region, which may decrease noise (Poldark, 2007).

Another option is to extract the data using *hemodynamic response extraction.* Here the HRF time-course for each condition across the ROI is estimated. Based on the time-course of an ROI, connectivity is calculated as the correlation of time series for all other voxels in the brain. This approach shows an entire estimated response in time rather than the fit of an assumed hemodynamic response. It can provide a more detailed and precise look at specific connectivity in the brain areas of interest (Margulies, et al., 2007). Plotting ROIs for each condition can help simplify the interpretation of activation as it can be difficult to discern the pattern of activity across conditions from an overall statistical parametric map. However, this approach can tend to over fit the data given the large number of parameters, this can result in estimated hemodynamic responses that are not physiologically plausible, particularly with small sample sizes (Poldark, 2007).

4.7.3. General linear model (GLM) approach.

The primary interest of most fMRI studies is to associate task related neural activity with brain regions; this is traditionally achieved with a GLM approach (Ashby, 2015). GLM is a confirmatory approach; it models the BOLD response of a single voxel across time as a linear combination of hypothesized response models plus an error term (Lindquist, 2008). The aim of the analysis is to test if the BOLD response in a voxel is unique to a condition or if the activity in the voxel is not task related.

4.7.4. Inter-subject correlation (ISC) analysis. Both controlled and free-behaviour designs in fMRI are needed although the latter still remains in the minority, as they are difficult to execute and analyse effectively (Maguire, 2012). ISC is a measure of shared BOLD activity across subjects over a period of time. This allows the exploration of sensory areas involved in natural viewing solely based on the similarities in BOLD responses across subjects (Kauppi, et al., 2014). It is conceptually a simple approach that avoids the use of an *a priori* stimulus time course model, because of this it circumvents a number of issues (e.g. task, stimulus duration and assumptions on criteria integration) and is a particularly effective method to investigate the processes of naturalistic viewing capturing the richness of the external world (Hasson, Malach, & Heeger, 2010).

The correlation coefficient method measures the similarity between fMRI time-series across multiple subjects by computing the mean voxel-wise correlation coefficients across all possible subject pairs. Considering this, the number of subject pairs increases quadratically with the correlation coefficient formula computed for each voxel within the brain, consequently, the analysis procedure is computationally demanding. In addition to this, ISC has been criticised for only capturing information about the variability of ISCs among participants as it simply averages the between subject correlation for each voxel. Consequently, the interesting features of the brain processing may be missed (Kauppi, et al., 2014). It is also important to note that the sluggish nature of the BOLD response can mean that rapid movie sequences are unsuitable for this method of data collection. Comparisons between GLM and ISC analysis methods have been conducted. Results revealed a high level of agreement between the methods with activations detected by ISC matching well with activations detected by GLM (ISC method is slightly more conservative than the GLM method; Kauppi, et al., 2014). The results also indicated that ISC was not susceptible to spurious findings, which could lead to over interpretation of the results (Pajula, et al., 2012). Comparisons demonstrate that ISC is a reliable method for detecting neural activity when data has been collected using a free viewing method.

4.8. Conclusion

fMRI brings physics and technology face-to-face with psychology, neuroscience, and medicine. This juxtaposition, whereby each domain has driven developments in the other, has been a source of excitement over the past twenty some years. As new experimental designs and methods are devised it will allow researchers to draw unique conclusions and increase the flexibility of fMRI. A much more detailed understanding of the cognitive neuroscience of mental robustness, together with appropriate behavioural markers is required. One interesting future direction for research would be to use fMRI techniques to examine the neural networks involved in mental robustness. This could provide some clarity relating to the genetic influences associated with the development of mental robustness. To date, very little research has employed fMRI to investigate mental robustness in military personnel. While a free viewing approach offers naturalistic advantages over a block and event-related task designs the novelty of this research approach within this complex field of research needs to be taken into account. To properly employ the free-viewing approach participants would need to be presented with a first person, continuous, unedited combat operational footage that also presents emotional challenges. While this may provide us with evidence of what regions of interest are activated when presented with certain footage this method does not lend itself well to task-based studies. This is because, without eye tracking, it would be difficult to identify exactly what in the scene had triggered a behavioural response without conducting a subjective analysis of the footage on a frame-by-frame basis. As such, a more conservative event-related approach is recommended at this early stage of research as it allows better control over confounding variables. The employment of an event-related task design would also provide the opportunity to directly compare findings with existing literature, which employed similar tasks involving military personnel (e.g. Paulus, et al., 2010). This would then allow for the identification of any consistent results or trends in the data.

Chapter 5

Neurocognitive processes underpinning different aspects of mental robustness in UK Armed Forces

5.1. Abstract

The research combined psychometric measures, behavioural and functional imaging to produce a deeper understanding of the underpinnings of mental robustness. The research recruited 31 serving personnel from the UK Armed Forces (UK AF), who had served in combat in the last five years. Data was collected both directly from participants and about participants from informants who had commanded them in recent operational deployments. Measures of individual difference relating to participants mental health and performance were collected. Sixty-four percent of participants were rated as having borderline to high post-traumatic stress symptoms (PTSS). Participants completed two fMRI-based tasks: Task 1 was a threat detection task, which assessed participant's ability to make decisions under pressure. The images were categorised as either MRp relevant (images of complex operational scenes) or MRec relevant (images of emotionally challenging operational scenes). Results indicated that MRec images resulted in a bias to shoot whether a threat was present or not. However, reward sensitivity (RS) was found to improve participants ability to discriminate between threat and non-threatening MRp images, but not MRec images. Increased activation in the amygdala was associated with increased frequency of hits and reduced false positive errors. Activation in the insula showed greater percentage signal change in the right insula to threatening images, but a more attenuated percent signal change in the left insula.

Task 2 employed an emotional Stroop task, preceded by a priming influence. This approach allowed us to investigate interference effects of combat relevant words on cognitive processing. Results found that participants showed longer colour naming latencies for combat related words compared to control words when primed with military footage. However, when primed with control footage participants showed longer colour naming latencies for control words. In contrast with previous research we found a negative correlation between reaction times and PTSS. These findings indicate that PTSS improved soldier's performance on the emotional Stroop task, allowing individuals to supress emotional arousal associated with military words.

Our brain imaging results support these findings with a negative relationship between PTSS and increased activity in the amygdala and antHC, regardless of task condition. This lack of activation in the limbic system was paired with increased activation in the vmPFC. More specifically, in the left vmPFC, increased activity was associated with control words while reduced activity was associated with military words.

This research furthers our understanding of the critical factors required for optimal military performance during deployment and how personnel are able to continue to perform post-deployment. The findings have practical implications for the military and could be used to inform pre-deployment training and post-deployment re-integration procedures.

5.2. Introduction

Mental robustness is a relatively stable disposition associated with an ability to deal with a wide variety of stressors and obstacles, and yet continue to function under pressure. It is important in many areas of life, but probably none more so than military environments. Soldiers are faced with unparalleled challenges during combat deployments relating to information management, decision-making, motor control and emotional control; all of which are critical both to mission success and survival (Carston & Gardner, 2009; Driskell, Salas & Johnston, 2006; Pori, Tušak & Pori, 2010; Ward, et al., 2015). Attentional lapses, narrowing of perceptual focus and/or biased information processing can result in errors and poor performance (Orasanu & Backer, 1996). In contrast, when soldiers return from operational deployment they are expected to reintegrate back into society and complete simple day-to-day tasks.

5.2.1 Predicting performance.

In a bid to understand and even predict how individuals are able to continue to perform, some researchers (e.g. Beattie, et al., 2017; Bell, et al., 2013; Hardy, et al., 2014) have turned to reinforcement sensitivity theory (RST; Gray, 1982). The theory is a major neuropsychological account for approach and avoidance motivations (Corr, 2008). It sees performance predicted by an individual's sensitivity to rewards or stimuli that imply the likelihood of a reward occurring (Reward Sensitivity or RS) and punishments or stimuli that implies the threat of punishment (Punishment Sensitivity or PS). Sensitivity to rewards are underpinned by the behavioural activation system (BAS), which is proposed to be responsible for all goal focused approach behaviour (Gray & McNaughton, 2000). Punishment is underpinned by the fight-flight-freeze system (FFFS), which is responsible for mediating all fear responses to aversive stimuli. Conflict between the BAS (approach) and FFFS (avoid) is resolved by the behavioural inhabitation system (BIS) by generating the emotion of anxiety.

This entails the inhibition of prepotent conflicting behaviours, the engagement of risk assessment processes, and the scanning of memory and the environment to help resolve concurrent goal conflict (Pickering & Corr, 2008). Research with military cadets found self-report scores of RS to be associated with high levels of performance and punishment, with poor performance in a military examination of tactical judgement in combat scenarios (Perkins, Kemp & Corr, 2007). This research suggests that reward sensitivity is related to various cognitions and behaviors which one might associate with mental robustness, whereas punishment sensitivity is related to cognitions and behaviors that appear to imply a lack of mental robustness.

5.2.2 Mental robustness and combat.

Soldiers experience multiple and varied stressors on a daily basis during combat operations. Recent mental robustness research with military populations has identified two combat relevant dimensions of mental robustness: (1) the ability to perform under pressure making effective life or death decision (henceforth MRp) and (2) the ability to successfully negotiate emotional challenges (such as exposure to death) without lasting impact on their mental health (henceforth MRec; Simpson, et al., in prep). In this conception, the two separable dimensions of mental robustness share in common the need to effectively handle negative or challenging contexts or events (e.g. pressure, trauma). Exploring these dimensions separately is particularly important given the links between sustained experience of, and reactivity to stress, and an increased risk of cognitive impairment associated with post-traumatic stress disorder (PTSD; Galea et al., 2002; Hoge et al., 2004).

5.2.3 Processing emotions.

A number of brain regions central in emotion processing have been implicated in research investigating robustness (see van der Werff, et al., 2013 for a review) and PTSD (e.g. Liberzon, et al., 1999). These regions are within the limbic system (the centre for emotion processing) and include: the amygdala, the hippocampus, the ventromedial prefrontal cortex (vmPFC) and the insula cortex (see *Figure 5.1*).

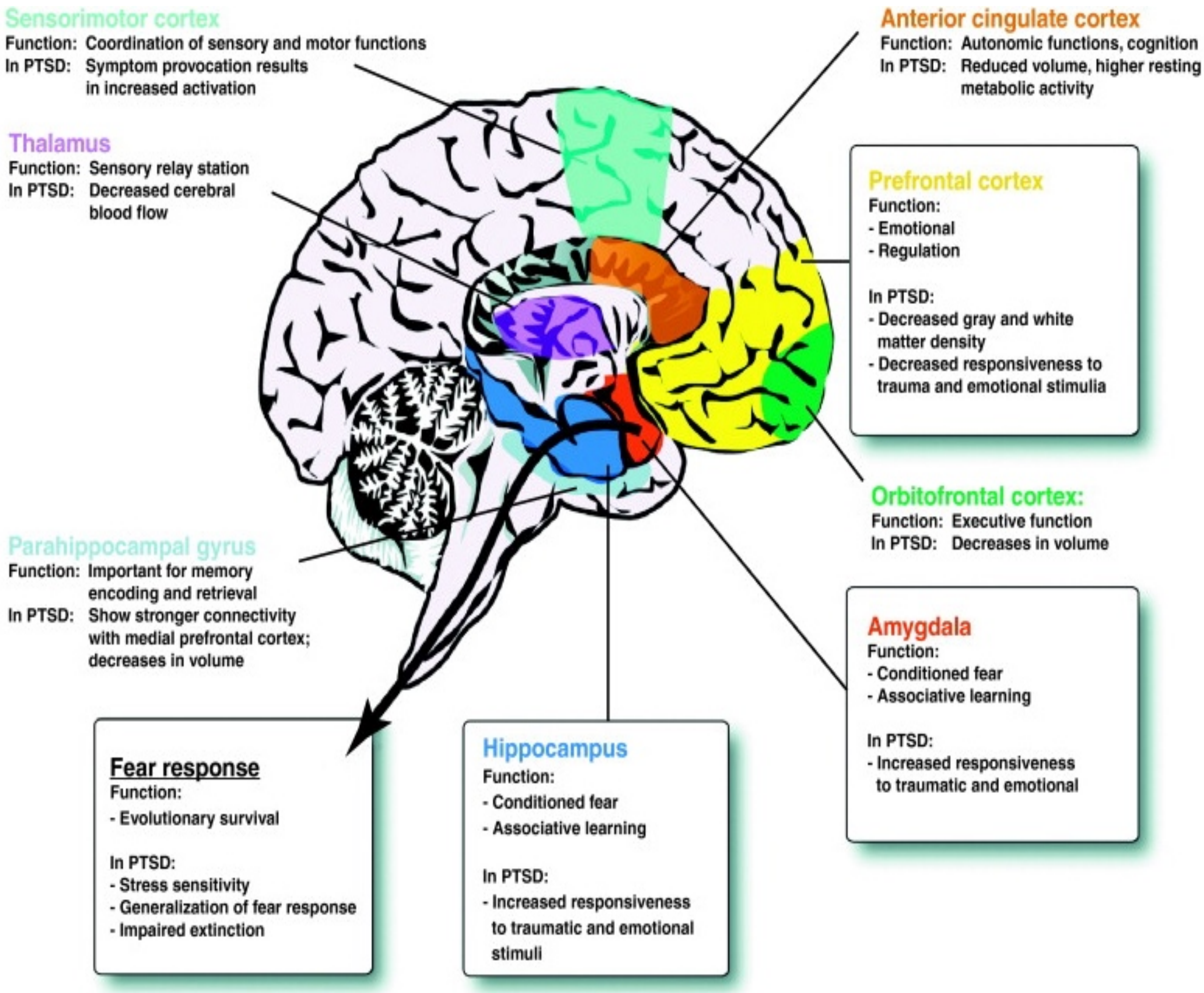

Figure 5.1. The human brain illustrating how the limbic system is involved in PTSD (Mahan & Ressler, 2011).

Amygdala. The amygdala is essential to the orchestration of arousal-related processes throughout the brain and body such as: mediating the fight-flight response to threat evaluating options, anticipating threats and rewards, and making decisions (Davis & Whalen, 2001; Morris, Ohman & Dolan, 1998; Seeley, et al., 2007; Whalen, et al., 1998). Research which employed a face-in-the-crowd task comparing patients with damage to the amygdala and a control group, found that patients were slower to identify angry faces than happy faces while the opposite effect was true in their control counterparts (Bach, Hurlemann, & Dolan, 2015). These findings indicate that human amygdala lesions impair prioritisation of threatening faces, providing evidence that the amygdala plays a causal role in responding to imminent danger (Bach, et al., 2015). The stress of combat exposure increases amygdala reactivity (van Wignen, et al., 2011). fMRI based research found veterans diagnosed with PTSD had exaggerated amygdala responses to general threat-related stimuli, suggesting that the amygdala plays a fundamental role in the pathophysiology of PTSD (Rauch, et al., 2000). Considering this, it is hypothesised that activation in the amygdala will increase when a threat is present; and that this increased activity will be positively correlated with rates of MRec and MRp, but more highly correlated with reported rates of PTSS.

Hippocampus. The hippocampus is a key component of the limbic system and is involved in explicit memory processes (Corcoran & Maren, 2001; Eichenbaum, 2000). Research has shown that the hippocampus is critical for episodic memory, (Squire & Zola-Morgan, 1991) and is involved in the encoding of context during fear conditioning. It does this by interacting with the amygdala during the encoding of emotional memories (Dolcos, LaBar & Cabeza, 2004; McGaugh, 2004). Extinction of fear is essential for a successful recovery from a traumatic experience and involves the unlearning of a fear reaction to situations that were previously associated with negative outcome, but currently can be considered as safe (Rothbaum & Davis, 2003). This strategy requires hippocampal-dependent memories to alter their response to the emotional stimuli.

Individuals suffering from PTSD experience memory related difficulties, for some it may be a difficulty in recalling certain parts of a traumatic event, alternatively some memories may be vivid. Due to the hippocampus' role in memory and emotional experience, it is thought that some of the problems individuals with PTSD experience may lie in the hippocampus. When the body experiences stress, cortisol is released to aid mobilization. However, studies have shown that high levels of cortisol damage cells in the hippocampus (Travis, et al., 2016). Imaging studies with military veterans have established a relatively consistent association between hippocampal volume reduction and impaired memory functioning, which can result in symptoms of avoidance/emotional numbing in individuals diagnosed with PTSD (e.g., Douglas, 1995; Gilbertson, et al., 2002; Grupe, et al., 2018, Gurvits, et al., 1996). Considering this, it is hypothesised that activation in the hippocampus will increase when a threat is present, and that this increased activity will be positively correlated with rates of MRec and MRp, yet negatively correlated with reported rates of PTSS.

Ventral medial prefrontal cortex (vmPFC). The vmPFC is involved in executive function and decision-making, particularly the regulation of emotional conflict (Etkin, et al., 2011). Research employing a gambling task saw participants asked to choose cards from 'risky' decks, that result in gradual debt over time, or cards from 'safe' decks, which result in a small overall profit (Bechara et al., 1994, 2000). The results found that patients with vmPFC damage were driven by the short-term benefits of the risky deck and failed to learn an advantageous strategy (Bechara et al., 1994, 2000). In contrast, research with controls examining conflict monitoring found that when conflict is detected, a regulatory system involving the PFC and dorsal anterior cingulate cortex (dACC), is engaged. This produces biased behaviour toward the goal-relevant response while suppressing incompatible responses (Kerns, et al., 2004).

Research examining the neural systems of fear extinction in nonhuman animals has also focused on the vmPFC (e.g. Lebron, Milad, & Quirk, 2004; Morgan, Romanski, & LeDoux, 1993; Quirk, Russo, Barron, & Lebron, 2000). The vmPFC was first implicated in fear extinction when Morgan et al. (1993) demonstrated that lesions to this region led to an impairment in extinction. Consistent with animal studies, fear conditioning or the expression of conditioned fear in healthy humans, has been associated with increased activation in the vmPFC (Phelps, Delgado, Nearing, & LeDoux, 2004). Extinction deficits have also been shown to play a role in PTSD, with several studies reporting significant negative correlations between vmPFC activation and PTSD symptom severity (reviewed in Hughes & Shin, 2011). Considering this, it is hypothesised that activation in the vmPFC will increase when a threat is present, and that this increased activity will be positively correlated with MRec and MRp, yet negatively correlated with reported rates of PTSS.

Insula cortex. The insula is sensitive to the representation of risk (for a review see Knutson & Bossaerts, 2007) and to the anticipation of pain (for a review see Ploghaus et al. 1999). Research aiming to predict soldiers' performance in extreme environments found a significant percent signal increase in the right insula, but an attenuated percent signal change in the left insula when personnel were presented with threat-related images compared to non-threat related images (Paulus, et al., 2010). This interaction effect suggests that expending more neurocognitive effort in general personnel conserves processing resources when faced with a non-threat stimulus attending only to threat-related stimulus. This neuropsychological tuning may allow them to protect emotional processing networks from being overloaded. Considering this, it is hypothesised that activation in the right insula will increase while activity in the left insula will decrease when a threat is present, and that this change in activity will be positively correlated with rates of MRec and MRp, yet negatively correlated with reported rates of PTSS.

5.2.4 Current research.

A better understanding of how individuals are able to continue to perform in complex extreme enviroments, that present potentially traumatic incidents, and how certain brain regions of interest may contribute to mentally robust behaviour, in order to better understand genetic influences. In the following experiment, we have developed two fMRI-based tasks to simulate (1) decision making during combat and (2) to examine the emotional interference effect combat can have on decision making during post-deployment. Task 1 is an operationally relevant threat detection task in which participants were required to attend to emotional aspects of the stimuli. Previous research with military personnel has presented stimuli where threats are not embedded (e.g. emotional faces task; Paulus, et al., 2010) and images are not combat relevant (e.g. International Affective Picture System) or emotionally challenging (Simmons, et al., 2011). Our threat detection task employs a more naturalistic approach, using complex and emotionally challenging images from recent operational deployments in Afghanistan, with threats embedded within the image.

Task 2 is an emotional Stroop task with a priming influence which requires participants to attend to the non-emotional aspects of the stimuli. This approach allowed us to investigate interference effects of combat relevant words on cognitive processing. Cognitive conflict can arise from this 'emotional interference' and can compromise the ability to complete tasks requiring cognitive control. Longer reaction times for identifying the colour of emotional words as compared to neutral words are regarded as a measure of emotional interference on cognitive control. Previous research suggests that mentally robust individuals have an enhanced ability to prevent unwanted information from interfering with current goals (Dewhurst, Anderson, Cotter, Crust & Clough, 2012). Research with military personnel found an attentional bias towards combat related words particularly in veterans with PTSD (Ashley, Honzel, Larsen, Justus, & Swick, 2013). To enhance the magnitude of the semantic meaning of the word and create more intense emotional conflict, participants were primed with either military relevant footage or control footage.

Together, these tasks may facilitate the development of an optimal processing model. This will allow us to understand the neural mechanisms underlying performance during combat and how soldiers filter out emotional interference during post deployment day-to-day life. Informant ratings of mental robustness and self-report measures of PTSS in addition to reinforcement sensitivity profiles were also measured to determine individual differences in cognitive functioning. Ideally, soldiers will be able to employ enhanced processes during combat (e.g. heightened sensitivity to threat) yet conserve processing resources when faced with non-threatening reminders of combat.

For simplicity, the threat detection task will be reported in full first followed by the emotional Stroop task. Each task has their own discussions with a final general discussion where we examine the overall findings of the research.

Task 1

5.3. Method

5.3.1 Participants.

Task 1 was divided into two parts: *Part 1* saw the recruitment of informants. These participants completed a measure of mental robustness about a soldier that served under them in the most recent operational deployment. The informing personnel's responses were kept confidential. *Part 2* saw the recruitment of the individuals who were reported on by the informants (known from now as "informees"). The informees completed a series of questionnaires before completing an MRI based task (see 'A' of *Figure 5.2.* for the scanner task order). Successful recruitment required all parties to agree to participate. The conditions for participation in the scanning element of the study included: amongst other criteria normal vision and hearing, no colour blindness, right handed, and no non-surgical metal in the body (e.g. shrapnel).

A total of 32 service personnel were recruited from the UK Armed Forces (UK AF); four served in the British Royal Marine Commandos (RM) and 28 served in the British Army. Seven of these personnel (1 RM and 6 Army) were recruited as informants. Informants' ages ranged from 29 to 47 years (M_{age} = 39.43, *SD* = 6.97) and had served in the UK AF for 7 to 31 years (M = 21.29, *SD* = 8.40). Service ranks ranged from Sergeant (NATO Code OR-3) to Major (NATO Code OF-3). Informants' reported educational attainment ranged from General Certificate of Secondary Education (GCSE; UK equivalent of the High School Diploma) to Master's degree, with 71 percent of informants attaining at least GCE Advanced Level (A Level). All informants had deployed on combat operations (M = 3.57, *SD* = 1.39) with at least one operational deployment in the past five years in a ground close combat role. Informants reported on between 1 and 12 (M = 3.57, *SD* = 3.86) personnel each.

Twenty-five informees (3 RMs and 22 Army) who served under the informants during an operational deployment in the last five years were recruited to take part in the imaging study. These participants age ranged from 23 to 46 years *(*M_{age} = 29.96, *SD* = 5.85) and had served in the UK AF for 5 to 30 years (M = 10.96, *SD* = 5.48). Ranks ranged from Private (NATO Code OR-1) to (late entry) Captain (NATO Code OF-2) with 60 percent of informees ranked Corporal (NATO Code OR-4) or lower. Informees reported educational attainment ranged from GCSE to Master's degree, with 21 percent of informees attaining A Level or higher. All informees had deployed on combat operations (M = 2.64, *SD* = 1.97) with at least one operational deployment in the past five years in a ground close combat role. Due to excessive head motion in the scanner task, two informees were excluded. The final sample consisted of 23 service personnel (1 RM and 23 Army) for the threat detection task. In the previous research a group difference in reported mental robustness between RMs and INF personnel was identified. Within this research it was not possible to recruit enough RMs due to unexpected operational deployments overseas, we were therefore unable to compare these groups within this research.

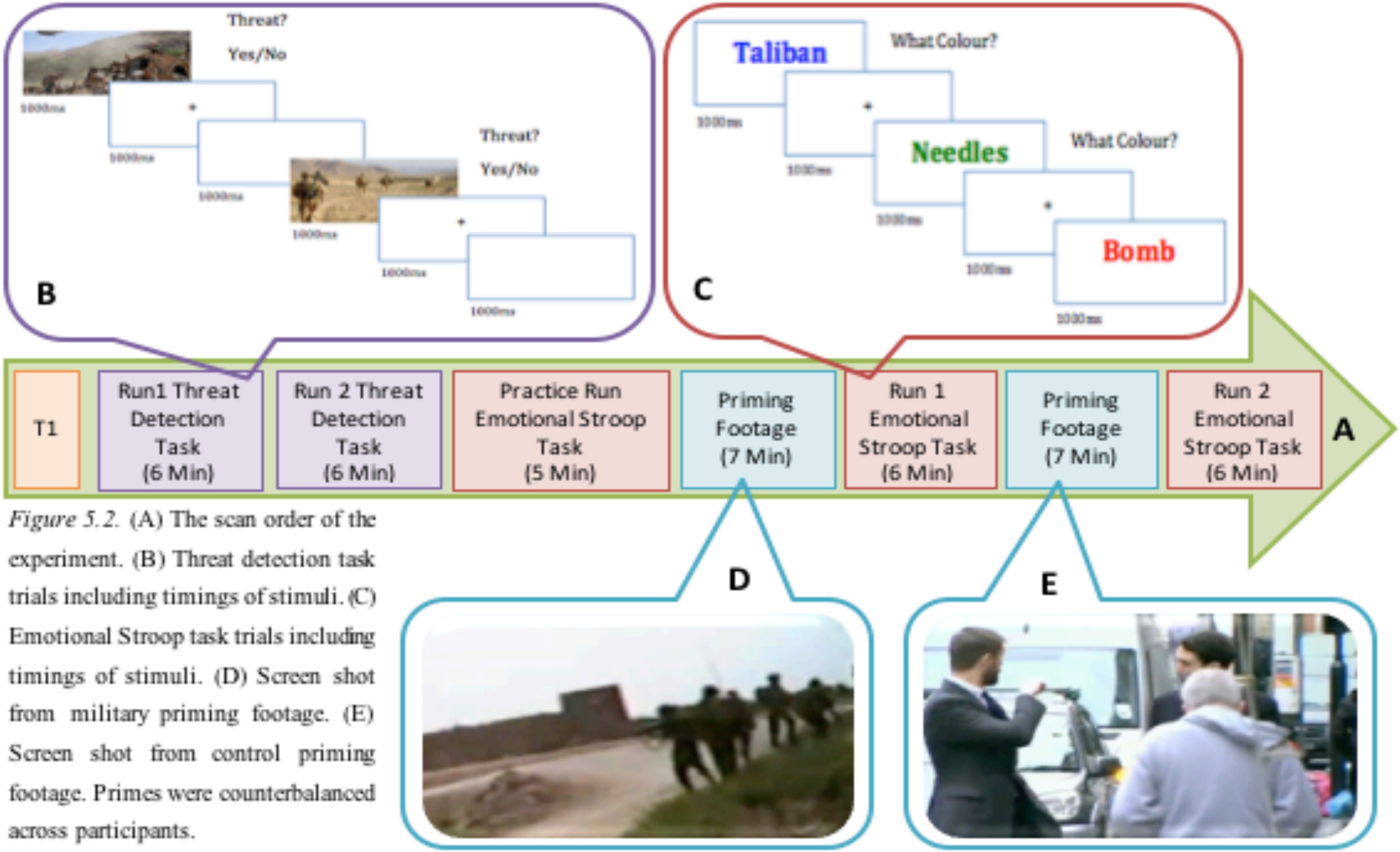

Figure 5.2. (A) The scan order of the experiment. (B) Threat detection task trials including timings of stimuli. (C) Emotional Stroop task trials including timings of stimuli. (D) Screen shot from military priming footage. (E) Screen shot from control priming footage. Primes were counterbalanced across participants.

5.3.2 Instruments.

Mental Robustness. We used the 12-item informant rated measure of mental robustness for military operations (MR-MO; Simpson, et al., in prep). The measure has two subscales with seven items assigned to assess mental robustness in relation to the emotional challenges combat presents (MRec) and five items assigned to assess mental robustness in relation to performance under pressure (MRp). Informants were asked to rate personnel who served under them on their most recent operational tour using the stem "*Based on my observations of Soldier 'X' while on an operational deployment, Soldier 'X' is able to maintain a high level of personal performance, even when:"*. Responses are based on a 7-point Likert scale that ranged from 1 (*"never")* to 7 *("always"*), with a midpoint anchor of 4 ("*sometimes"*), a "*not applicable"* option was also available as participants were instructed that responses should be based on actual experiences. Scores on the MRec subscale ranged from 22 to 45 with a mean score of 37.5 (*SD* = 6.00). Scores on the MRp subscale ranged from 22 to 32 with a mean score of 27.40 (*SD* = 3.67).

Post-Traumatic Stress. In line with ethical approval all participants were screened for Post-Traumatic Stress Symptoms (PTSS) using the PTSD Checklist–Military (PCL-M; Weathers, Huska & Keane, 1991). This 17-item self-report measure assesses the DSM-IV symptoms of PTSD. Responses are based on a 5-point Likert scale that ranged from 1 (*"not at all")* to 5 *("extremely"*) to indicate the degree to which they have been bothered by that particular symptom over the past month. Scores range from 17 to 85, and can be categorized as *no symptoms,* 18-33 are categorized as *normal,* scores of 34-43 as *borderline* and 44-85 as *high.* Scores above 44 indicate that a participant may have PTSD or trauma related problems and further investigation of trauma symptoms might be warranted.

For informants PCL-M scores ranged from 20 to 71 with a mean of 31.71 (*SD* = 17.80). One informant was classed as having a high level of PTSS. According to approved procedures he was signposted to both military and civilian organisations that provide assistance to personnel suffering from PTSS. As individuals exposed to trauma are susceptible to altering their retrospective reports of events (McNally, Lasko, Macklin, & Pitman, 1995; McNally, Litz, Prassas, Shin, & Weathers, 1994; Schwarz, Kowalski, & Mcnally, 1993), we were concerned that PTSS may affect informant ratings of the MR-MO. Results showed no significant difference between informant ratings by the participant classed as high and informants classified as borderline or normal (all *p's => .96*). Considering this, we did not remove his responses from the analysis.

Informee PCL-M scores ranged from 22 to 57 with a mean score of 38.72 (*SD* = 10.65) on the PCL-M. Eight informees' scores were classified as high, eight as borderline and nine as normal, as with the informants, informees classified as high were signposted to appropriate organisations for further assistance.

Anxiety and depression. Levels of anxiety and depression were assessed in informees using the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983). This 14-item self-report measure has seven items assigned to each of the anxiety and depression subscales. Responses are based on a 4-point Likert scale that ranged from 0 ("most of the time") to 3 ("not at all"), depression items were scored (0-1-2-3) and anxiety items are reverse scored (3-2-1-0). Subscale scores are typically categorised to indicate the level of anxiety or depression experienced where scores of less than 8 are categorised as *normal*, scores of 8–10 as *borderline*, and scores of 11–21 is considered a *clinically significant* disorder. Research has shown that the Cronbach alpha for HADS-Anxiety ranges from 0.68 to 0.93 (adequate to excellent) with a mean of 0.83 (very good). Cronbach alpha for HADS-Depression ranged from 0.67 to 0.90 (adequate to excellent) with a mean of 0.82 (very good).

Scores on the anxiety subscale ranged from 8 to 18 with a mean score of 13.50 (*SD* = 2.87). Twenty-one informees were classified as having high levels of anxiety and four informees were classified as borderline. Scores on the depression subscale ranged from 7 to 18 with a mean score of 12.04 (*SD* = 2.36). Twenty-one informees were classified as having high levels of depression, three informees were classified as borderline and one participants score was classified as normal.

Reward and punishment sensitivity. Informee reinforcement sensitivity was assessed using Corr's (2001) transformations of the Eysenck Personality Questionnaire – Revised Short Scale (EPQ-RS; Eysenck, Eysenck & Barrett, 1985). The EPQ-RS compromises 48 items (12 for each of the traits of neuroticism, extraversion, and psychoticism and 12 for the lie scale), scores can range from 0 to 48 for reward sensitivity and 12-48 for punishment sensitivity. Responses were based on a forced choice format that have to be answered "yes" or "no". In order to use the EPQR-S to measure reward and punishment sensitivity, Corr (2001) proposed the following transformations: reward sensitivity = (E x 2) + N + P), and punishment sensitivity = (12 – E) + (N x 2) – P), where E = extraversion, N = neuroticism, and P = psychoticism. Scores were therefore free to range from 0 to 48 for reward sensitivity and from –12 to 36 for punishment sensitivity. Informee scores of reward sensitivity ranged from 14 to 39 with a mean score of 27.76 (*SD* = 4.97) and scores of punishment sensitivity ranged from -4 to 27 with a mean score of 11.20 (*SD* = 8.76). Descriptive statistics for each instrument at and overall and item level are presented in Appendix C.

5.3.3 Materials.

Stimuli for Task 1 consisted of 108 colour images. Thirty-six images were categorised as emotionally challenging combat operational scenes, thirty-six images were categorised as complex operational scenes and thirty-six neutral images were presented. The combat relevant images were presented both with and without an embedded threat added. The 72 threats edited into the images all met the rules of engagement criteria as they posed a direct and immediate threat to the life of soldier, fellow comrades or civilians depicted in the scene. The combat relevant images were counterbalanced across runs so participants did not see both the original and edited image within the same run. The neutral images presented were matched to the operational images on: number of individuals in the scene, direction of movement, landscape and any key features such as vehicles (see *Figure 5.3*). Images were presented in the middle of the screen. The on-screen dimensions of all images were set at 192mm x 120mm.

Figure 5.3. Examples of the images presented in Task 1 both with and without threats and one of their equivalent matched neutral

5.3.4 Procedure.

Ethical approval was obtained from the Ministry of Defence Research Ethics Committee (MoDREC) as well as institutional ethical approval. All potential participants (who had deployed in a ground close combat role in the last five years) attended a recruitment presentation on the current research. Personnel interested in taking part, as either an informant or as an informee for the scanning element of the study, were then given a research information sheet and consent form and given 24 hours to consider their participation. Recruitment then took two approaches:

Approach 1 - personnel who identified themselves as informants and who chose to consent then provided researchers with a list of serving personnel who had deployed under their command in their most recent deployment. The researcher then contacted these personnel and if they hadn't already attended a research presentation then they would be invited to attend one. Once they had attended a presentation these personnel were then given a research information sheet and consent form and given 24 hours to consider their participation as an informee.

Approach 2 - personnel who identified themselves as informees, met the MRI safety screening criteria and consented to take part in the study were then asked to identify a serving soldier who commanded them on their most recent deployment. The researcher then contacted the commander and if they hadn't already attended a research presentation then they would be invited to attend one. Once they had attended a presentation the commanders were then given a research information sheet and consent form and given 24 hours to consider their participation as an informant.

Once a pairing had been made with both the informant and informee consenting to take part then informants were given a short questionnaire to complete about themselves and about the individual(s) who served under them. On receipt of the completed questionnaires from the informants then informees were booked to attend Bangor Imaging Unit. Once at the unit informees completed a short questionnaire about themselves before taking part in the MRI based tasks.

Brain images were acquired with a Philips Achieva 3.0-T scanner with a 32-channel head coil. BOLD contrast functional images were collected with a T2*-weighted, gradient echo planar image (EPI) sequence (TR = 2000ms, flip angle=90° with a voxel size of 3 x 3 x 3.5mm^3). Stimuli were displayed on a Cambridge Research System BOLD screen located behind the scanner bore and were viewed via a mirror fixed to the head coil. Presentation of the stimuli was controlled by Psychtoolbox (Brainard, 1997) running on MATLAB (Mathworks inc., 1998).

All tasks employed an event related design. The threat detection task was comprised of two runs with three blocks in each run. Within each block there were 36 trials: 12 emotionally challenging scenes (six with and six without threats), 12 complex operational scenes (six with and six without threats) six neutral scenes and six fixation trials. Fixation trials (or null events) were included as they were used as the baseline hemodynamic response for the stimulus trials. This was obtained by subtracting the event-related average of the non-event trials from the average of the event types of interest. Images were presented for 1000ms followed by a fixation for 1000ms. Participants were instructed to respond via button press during this 2000ms period to indicate whether they would shoot or not (right button = shoot, left button = don't shoot). A blank screen was then presented for 1000ms before the next trial began (see 'B' of *Figure 5.2.* for a schematic of a trial).

Upon completion of the tasks participants were provided with a debrief form which gave a brief overview of the research they had taken part and provided information to services provided by the military and organisations outside the military should the study have raised any personal issues. In line with MODREC a clinical psychologist reviewed all questionnaires where scores on the PCL-M were above the threshold. If deemed necessary the clinical psychologist would contact these individuals directly to discuss possible further assessment.

5.3.5 Data pre-processing.

All data were analysed with the SPM12 (statistical parametric mapping) software package (http://www.fil.ion.ucl.ac.uk/spm). Images from each functional run were realigned to the first image of the run then co-registered to the normalised anatomical T1. This transformation was then applied to the functional images to facilitate transformation into MNI space. Finally, the normalised functional images were smoothed in order to mitigate the effects of residual spatial transformation noise.

5.3.6 Behavioural data analysis.

Reaction times in milliseconds (ms) were recorded for every valid trial in which the speed of the response fell within the allotted window (2000ms). Responses faster than 100ms were coded as missing (invalid) data. Prior to any analysis each participant's mean reaction to neutral images was calculated. The neutral mean reaction times were then subtracted from the reaction times of each the MRec images (with and without threat) and MRp images (with and without threat). This provided us with reaction times for each condition specifically relating to 'military' stimulus.

Responses were coded into four different types: (1) correct detection (hit) responses occurred when the participant made a correct decision to shoot when a threat was present. (2) Correct rejection responses occurred when the participant made a correct decision not to shoot when there was not a threat present. (3) Misses occurred when the participant made an incorrect decision not to shoot when a threat was present. Finally, (4) false positive error (false alarm) responses occurred when the participant made an incorrect decision to shoot when there was no threat present. Frequency counts for each type of response were tallied across participants for each condition. These counts were converted into percentages by dividing the frequency counts by the number of trials of that type.

In addition to the computed percentages of errors and correct responses, measures of signal detection bias and sensitivity were computed for the hits (correct detections) and false alarms (false positive errors). Proportions of both the hits and false alarms were converted to z-scores across each of the military stimulus conditions. Bias was calculated as c, which represents the sum of the z-scores for hits and false alarms. This sum is then multiplied by a factor of −.5 (see Macmillan & Creelman, 1991). Negative bias scores indicate a more liberal criterion for the shoot/don't shoot response, while positive bias scores indicate a more conservative criterion. Signal detection sensitivity was calculated as d', which represents the z-scores for hits minus the z-scores for false alarms. Higher sensitivity scores indicate greater accuracy in detecting threats, lower sensitivity scores indicate less accuracy. Together, these measures provide estimates of the discriminability (d') of the threat/no threat, as well as an estimate of the tendency to set a lower criterion (c) for making the shoot/don't shoot response for each participant. Correlations of these measures with reaction time were performed to evaluate the relationships between bias, sensitivity, threat perception, and cognitive control during the decision to shoot.

5.3.7 Region of interest (ROI) analysis.

Rather than doing a whole-brain voxel wise analysis, a set of pre-determined anatomical ROIs (amygdala, anterior hippocampus (antHC) and insula) were used to extract estimates of evoked signal within a particular region of the brain. We defined a priori anatomical regions based on previous findings (Amygdala, van Wignen, et al., 2011; AntHC, Rothbaum & Davis, 2003; Insula, Paulus, et al., 2010). To do this we identified coordinates related to these regions (see *Table 5.1*) and used these to define a set of voxels in each participant that comprised their ROI. Five mm radius spherical ROIs were defined using the MarsBaR ROI toolbox (Brett, et al., 2002). The time courses for each ROI from each participant were then extracted. This raw time course was then converted into percent signal change for each condition with the following transformation: (condition – fixation)/fixation x 100. The peak activations for each condition were then extracted. The average peak brain activation to neutral images was subtracted from the average peak activations of the other conditions for each ROI. This gave an average neural activation that is specifically related to the 'military' image conditions. Repeated measures ANOVAs were used to identify effects of Image Type (MRec, MRp) and Threat Presence (threat, no threat).

A difference-in-differences (DiD) score was also calculated for each ROI to allow us to examine the effect of measures of individual differences (e.g. PTSS) on brain activation that are not related to the task conditions. The DiD score was calculated with the following transformation: (MRec Threat Present – MRec No Threat) – (MRp Threat Present – MRp No Threat).

Table 5.1. Previously reported anatomical MNI coordinates for the ROIs used in the threat detection task.

	Previously reported coordinates						
	Left			Right			
	x	y	z	x	y	z	Reference
Amygdala	-24	0	-21	21	-1	-22	Papademetris, et al 2006
AntHC	-31	-3	-25	28	-13	-26	Barenese, et al., 2011, 2010
Insula	-42	4	-1	44	4	0	Papademetris, et al 2006

5.4. Results

5.4.1 Behavioural results.

Error rates. False positive error responses in the threat detection task indicate a decision to shoot when there is not threat present. A total of 164 false positive error responses were made across the 23 participants. Three participants made no false positive errors. One made no false positive errors when presented with MRec images and two made no false positive errors when presented with MRp images. To calculate participants sensitivity (d') and bias (c) to threats participants rate of false positive errors needs to be converted into a z-score which cannot be done with rates of 0 as the corresponding z-score would be -∞. The most common solution (for review see Stanislaw & Todorov, 1999) and the one employed here is to replace rates of 0 with $0.5 \div n$, and rates of 1 with $(n - 0.5) \div n$, where n is the number of trials (Macmillan & Kaplan, 1985). Error rates for each stimulus condition are presented in *Table 5.2.*

Table 5.2 Valid response measurements in the threat detection task as a function of image type.

	Image type	
Response types	MRec	MRp
No threat present		
False positive errors		
Percentage	11.11%	8.09%
Mean RT	1099 ms	1095 ms
Correct rejections		
Percentage	86.23%	87.31%
Mean RT	1092 ms	1109 ms
Threat present		
Misses		
Percentage	32.36%	34.54%
Mean RT	1135 ms	1166 ms
Correct detections		
Percentage	60.38%	62.07%
Mean RT	986 ms	971 ms

To understand which image type was most likely to elicit a response error, a within-subjects 2 (Image Type: MRec, MRp) X 2 (Response: false positive errors, miss) ANOVA was conducted. Results revealed no main effect of Image Type (F(1,22)=.17, p=.68) but a main effect of response (F(1,22)=50.89, p=<.001). A simple effects analysis comparing the difference between Response within the Image Type revealed a significant difference between false positive errors and misses in MRec images (p=<.001) and in MRp images (p=<.001). A significant interaction effect was also revealed (F(1,22)=5.46, p=.02) with MRec images producing more false alarm responses while MRec images produced more miss responses.

A simple effects analysis comparing the difference between Image Type revealed a significant difference between MRec (p=<.001) and MRp (p=<.001). Results also revealed a significant main effect of response (F(1,19)=32.27, p=<.001). A simple effects analysis comparing the difference between responses revealed a significant difference between false positive errors (p=.05) but not miss responses (p=.11). No significant interaction effect was revealed (F(1,22)=.06, p=.80).

Reaction times. To understand which stimulus type participants were quickest to respond to the impact of Image Type (MRec, MRp) and Threat Presence (threat, no threat) on participant reaction times was examined. Participants were quickest to respond (after subtracting neutral reaction times) when presented with threatening images (MRp, Mean = 89.35 ms, SD = 138.80; MRec, Mean = 104.23 ms, SD = 155.66) than non-threatening images (MRp, Mean = 225.18, SD = 140.12; MRec, Mean = 210.21 ms, SD = 126.85). A within subjects 2 (Image Type: MRec/MRp) x 2 (Threat Presence: threat/ no threat) ANOVA revealed a significant main effect of threat presence (F(1,22)=28.22, p=<.001). A simple effects analysis comparing the difference between Threat Presence conditions within the Image Type condition revealed a significant difference between threat present and no threat in MRec images (p=.001) and MRp images (p=.001). However, there was no significant main effect of Image Type (F(1,22)=.01, p=.90) and no interaction effect (F(1,22)=.54, p=.47; see *Figure 5.4.*).

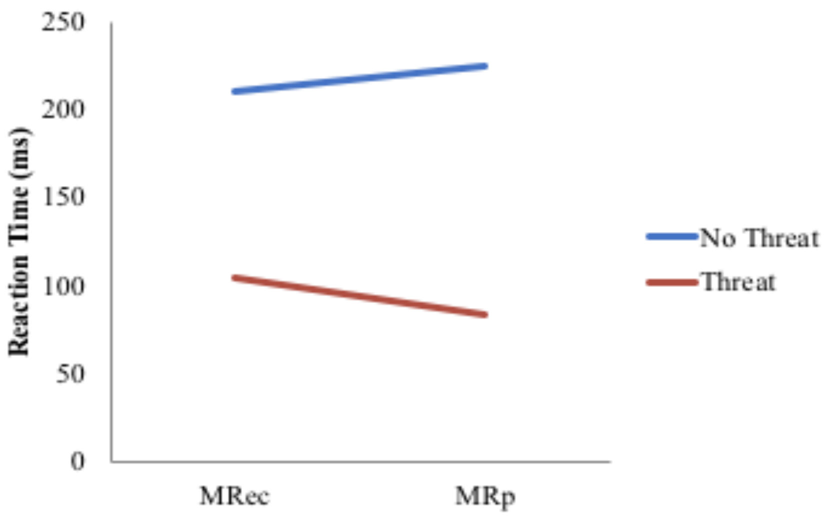

Figure 5.4. Mean reaction times as a function of Image Type (MRec vs. MRp) and Threat Presence (threat vs. no threat). Shoot responses were faster for threat present MRp images than threat present MRec images, whereas don't shoot responses were faster for no threat MRec images than no threat MRp images.

To understand if there was a speed-accuracy trade-off, a correlation analysis between false positive reaction times and false positive error rates was conducted. Results revealed a negative significant relationship ($r(22)= -.361$, $p=.039$) indicating a bias in the decision to shoot. This leads to faster and more accurate shoot responses when a threat is present, but it also leads to faster and erroneous shoot responses to images that do not include a threat.

Signal detection data. The converted *z*-scores for each image type condition along with signal detection bias (*c*) and sensitivity (*d'*) measures are shown in *Table 5.3*. The bias scores were marginally higher for MRp images ($c = .59$) than for MRec images ($c = .54$) indicating more conservative criteria for making a "shoot" response when presented with an MRp image and a more liberal criteria for making a "shoot" response when presented with an MRec image. The measure of bias across Image Type was significant: $r(22)= .88$, $p=<.001$. Sensitivity, as measured in signal detection, is independent of bias, and it reflects the discriminability of the stimuli. Threats were more discriminable when presented in MRp images (*d'* = 1.83) than MRec images (*d'* = 1.64), however, the difference in sensitivity across Image Type was not significant: $t(22)= 1.72$, $p=.09$

Table 5.3. Signal detection bias and sensitivity measures as a function of Image Type.

	Image Type	
Scores	MRec	MRp
False alarms (*z*)	-1.33	-1.46
Hits (*z*)	.27	.31
Bias (*c*)	.52	.57
Sensitivity (*d'*)	1.60	1.78

Notes: $n = 23$. $c = -.5*(z_H + z_{FA})$. $d' = z_H - z_{FA}$.

Measures of individual difference. A correlation analysis was conducted to establish the relationship between behaviour and measures of individual differences associated with military service, mental health and performance. To correct for the use of multiple correlations, a Bonferroni's correction were employed. Results revealed a significant positive relationship between *d'* and RS ($p= .01$). They also included a significant positive relationship between number of deployments and educational attainment ($p= .02$), PTSS ($p= .05$), and MRec ($p= .007$). A significant negative relationship between PTSS and MRp was also revealed ($p= .03$). No significant positive relationship between performance and measure of MRp or MRec were found.

Table 5.4. Correlation matrix of threat detection task behavioural and measures of individual difference.

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1 False Positive Errors (*z*)	-											
2 Hit (*z*)	.24	-										
3 Bias (*c*)	**-.80****	**-.77****	-									
4 Sensitivity (*d'*)	**-.65****	**-.57****	.07	-								
5 No. Deploy	.04	-.08	.02	-.09	-							
6 EduA	-.14	-.18	.21	-.02	**.48***	-						
7 PTSS	-.07	-.14	.13	-.05	**.41***	.04	-					
8 Depression	-.37	-.03	.26	.28	-.40	.21	-.39	-				
9 Anxiety	.24	.19	-.28	-.04	-.003	.35	**-.45***	-.01	-			
10 MRp	-.20	-.22	.28	-.008	.37	.33	**-.44***	-.08	.31	-		
11 MRec	.02	-.24	.13	-.21	**.54****	**.43***	-.05	-.24	.10	**.53****	-	
12 PS	-.14	.09	.03	.19	.03	-.27	.38	**-.42***	-.29	-.28	-.37	-
13 RS	-.39	.23	.11	**.50***	-.07	-.16	.08	**.49****	-.14	-.28	-.38	-.08

NB: n=23 for all variables. No. Deploy= Number of Deployments, EduA= Educational Attainment, PTSS= Post traumatic stress symptoms, MRp= Mental robustness pressured performance, MRec= Mental robustness emotional challenges, PS= Punishment Sensitivity, RS= Reward Sensitivity.

* = p<.05, ** = p<.01.

To further understand the relationship between RS and *d'* we performed a correlation analysis examining the relationship between MRec *d'* scores and RS and MRp *d'* scores and RS. Results revealed a significant positive relationship between MRp *d'* and RS (*r*= .54, *p*= .008) but not a significant relationship between MRec *d'* and RS (*r*= .32, *p*= .12). These results indicate that RS significantly improves the ability to discriminate between whether a threat is or is not present in MRp images, but not in MRec images.

5.4.2 Neuroimaging results

Previous research suggests a pattern of neural tuning in elite soldiers associated with threat detection and selective attention involving the amygdala, hippocampus and the insula (Paulus, et al., 2003; Paulus, et al., 2010; Simmons, et al., 2011; van Wignen, et al., 2011). Considering this, these three brain regions were chosen as ROIs for Task 1.

A correlation analysis was conducted to examine the relationship between measures of individual difference and difference-in-differences (DiD) activation in each ROI. Response bias was found to be positively correlated with activation in the right amygdala, although this was only approaching a significant realtionship (*p*=.06), and educational attainment was also positively correlated with activation in the left insula (*p*=.02). As hypothesised, ratings of MRec and MRp were positively correlated with activation in all of the ROIs examined, however none of the findings were found to be significant. See *Table 5.5.* for correlations between measures of individual difference and DiD activation in each ROI).

Table 5.5. Threat detection correlation results between responses, measures of individual difference and DiD activation in each ROI.

	Left Amygdala	Right Amygdala	Left AntHC	Right AntHC	Left Insula	Right Insula
1 False Positive Errors (*z*)	-.12	-.36	-.12	-.26	-.21	-.15
2 Hit (*z*)	.02	-.25	.05	-.34	-.11	-.15
3 Bias (*c*)	.06	.39	.05	.39	.21	.19
4 Sensitivity (*d'*)	.12	.10	.14	-.05	.09	.006
5 No. Deploy	.33	-.02	.27	.18	.34	.25
6 EduA	.09	-.05	.26	.20	**.45***	.30
7 PTSS	-.02	-.07	-.05	-.003	-.01	-.01
8 Depression	-.28	-.19	-.26	-.24	-.05	-.16
9 Anxiety	-.25	-.22	.13	.12	.33	.22
10 MRp	.22	.18	.27	.26	.30	.26
11 MRec	.23	.09	.04	.19	.03	.05
12 PS	.37	.37	.19	.01	.04	.10
13 RS	-.22	-.16	-.05	-.08	.12	.001

NB: n=23 for all variables. No. Deploy= Number of Deployments, EduA= Educational Attainment, PTSS= Post traumatic stress symptoms, MRp= Mental robustness pressured performance, MRec= Mental robustness emotional challenges, PS= Punishment Sensitivity, RS= Reward Sensitivity. * = p<.05.

The impact of Image Type (MRec, MRp) and Threat Presence (threat, no threat) on the mean of peak hemodynamic response function (HRF) percent signal change in each ROI was also examined. In the left amygdala, a repeated measures ANOVA found no main effect of Image Type ($F(1,22)=.73$, $p=.40$) but a main effect of Threat Presence ($F(1,22)=8.15$, $p=.009$). To explore the nature of the main effect, a simple effects analysis examining the difference between Threat Presence (threat/ no threat) within Image Type was conducted. Results revealed a significant difference between threat and no threat in MRp images ($p=.02$) but not in the MRec images ($p=.22$). There was no significant interaction effect ($F(1,22)=.68$, $p=.41$) between conditions (see *Figure 5.5.* for mean of peak HRF for each condition and average HRF curve).

In the right amygdala positive percent signal change was present in all conditions. A repeated measures ANOVA found no significant main effect of Image Type ($F(1,22)=3.33$, $p=.08$), no significant main effect of Threat Presence ($F(1,22)=.14$, $p=.70$) and no significant interaction effect ($F(1,22)=.13$, $p=.72$; see *Figure 5.5*. for mean of peak HRF for each condition and average HRF curve).

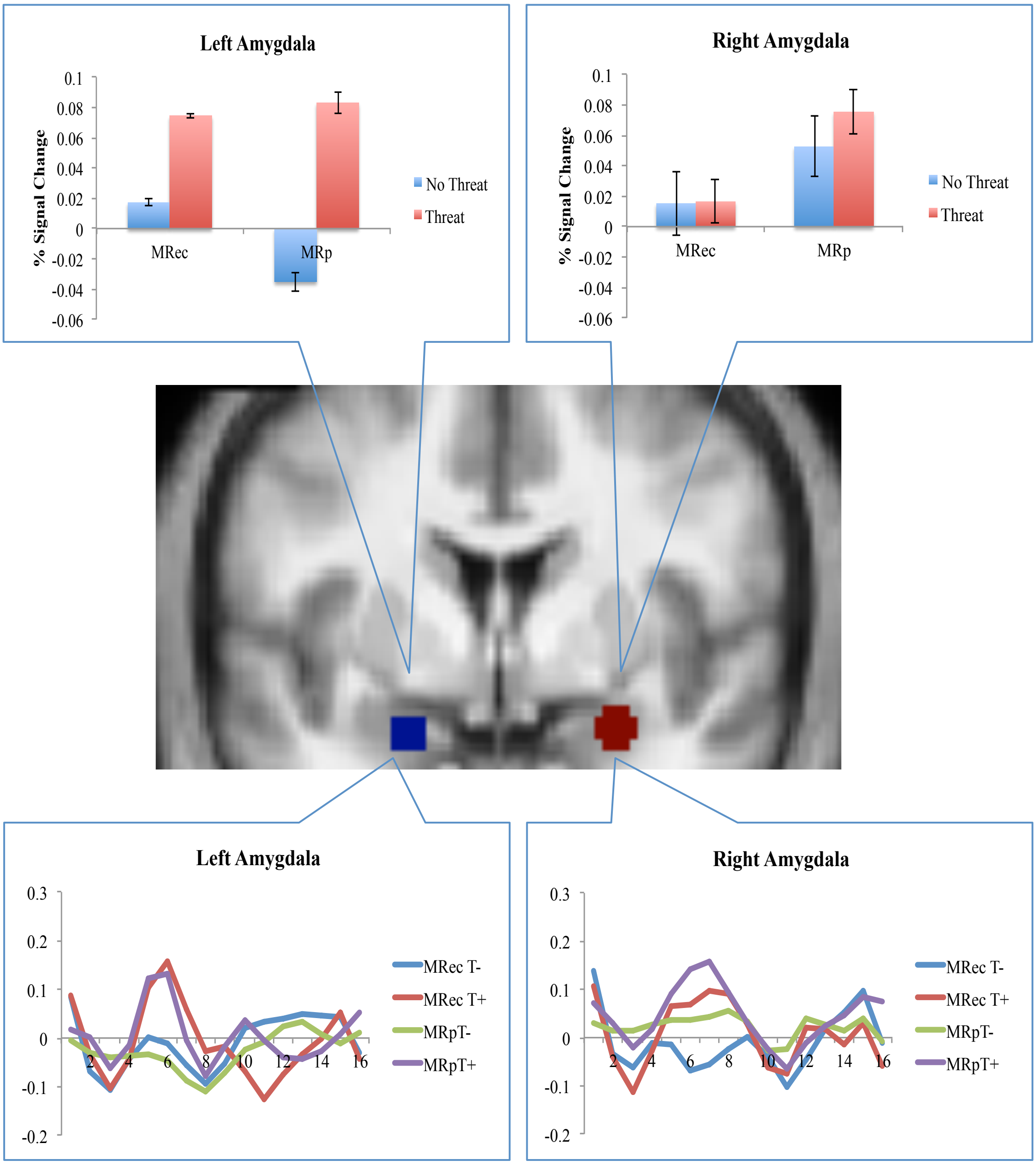

Figure 5.5. Mean peak evoked responses from the Threat Detection Task in the left and right amygdala as a function of Threat Presence (threat or no threat) and Image Type (MRec or MRp) and corresponding mean HRF curves.

In the left antHC, positive percent signal change was present across all conditions. A repeated measures ANOVA found no main effect of Image Type ($F(1,22)=1.38$, $p=.25$), no significant main effect of Threat Presence ($F(1,22)=1.58$, $p=.22$) and no significant interaction effect ($F(1,22)=.42$, $p=.51$; see *Figure 5.6.* for mean of peak HRF for each condition).

In the right antHC a repeated measures ANOVA found no main effect of Image Type ($F(1,22)=1.05$, $p=.31$), no significant main effect of Threat Presence ($F(1,22)=.005$, $p=.94$) and no significant interaction effect ($F(1,22)=.11$, $p=.73$; see *Figure 5.7.* for mean of peak HRF for each condition). The HRF for both hemispheres did not respond very strongly on average to the task stimulus (see *Figure 5.6.* for average HRF curves).

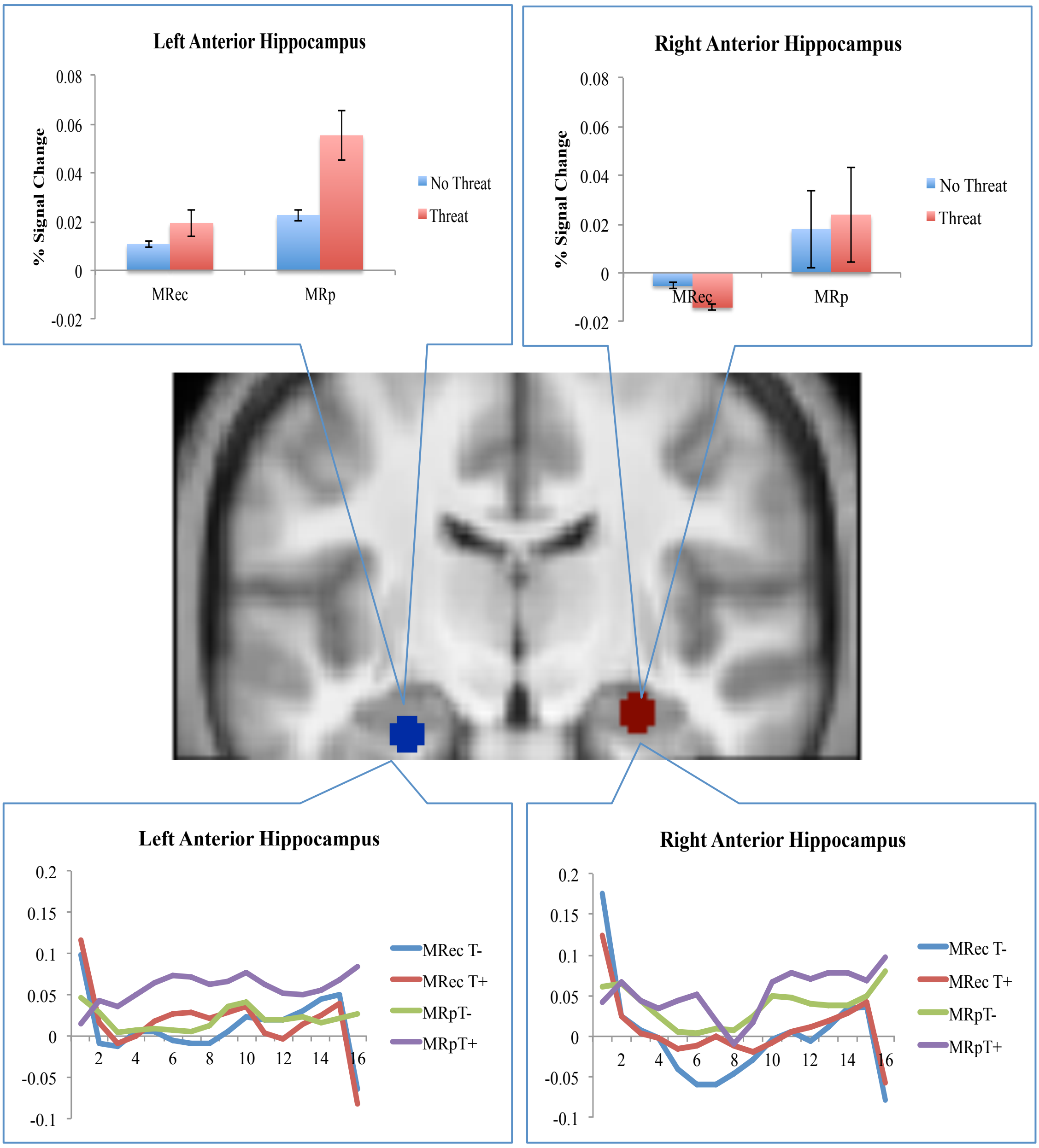

Figure 5.6. Mean peak evoked responses from the Threat Detection Task in the left and right anterior hippocampus as a function of Threat Presence (threat, no threat), and Image Type (MRec, MRp) and corresponding mean HRF curves.

In the left insula, a repeated measures ANOVA found no significant main effect of Image Type ($F(1,22)=1.10$, $p=.30$) but a significant main effect of Threat Presence ($F(1,22)=7.21$, $p=.01$). To explore the nature of the main effect, a simple effects analysis examining the difference between Threat Presence (threat/ no threat) within Image Type was conducted. Results revealed a significant difference between threat present and threat not present images in MRec images ($p=.05$) but not in MRp images ($p=.11$). There was no significant interaction effect ($F(1,22)=.05$, $p=.81$) between conditions (see *Figure 5.7.* for mean of peak HRF for each condition and average HRF curve).

In the right insula, a repeated measures ANOVA found no main effect of Image Type ($F(1,22)=.91$, $p=.34$), no significant main effect of Threat Presence ($F(1,22)=.40$, $p=.53$) and no significant interaction effect ($F(1,22)=.002$, $p=.96$; see *Figure 5.7.* for mean of peak HRF for each condition and average HRF curve).

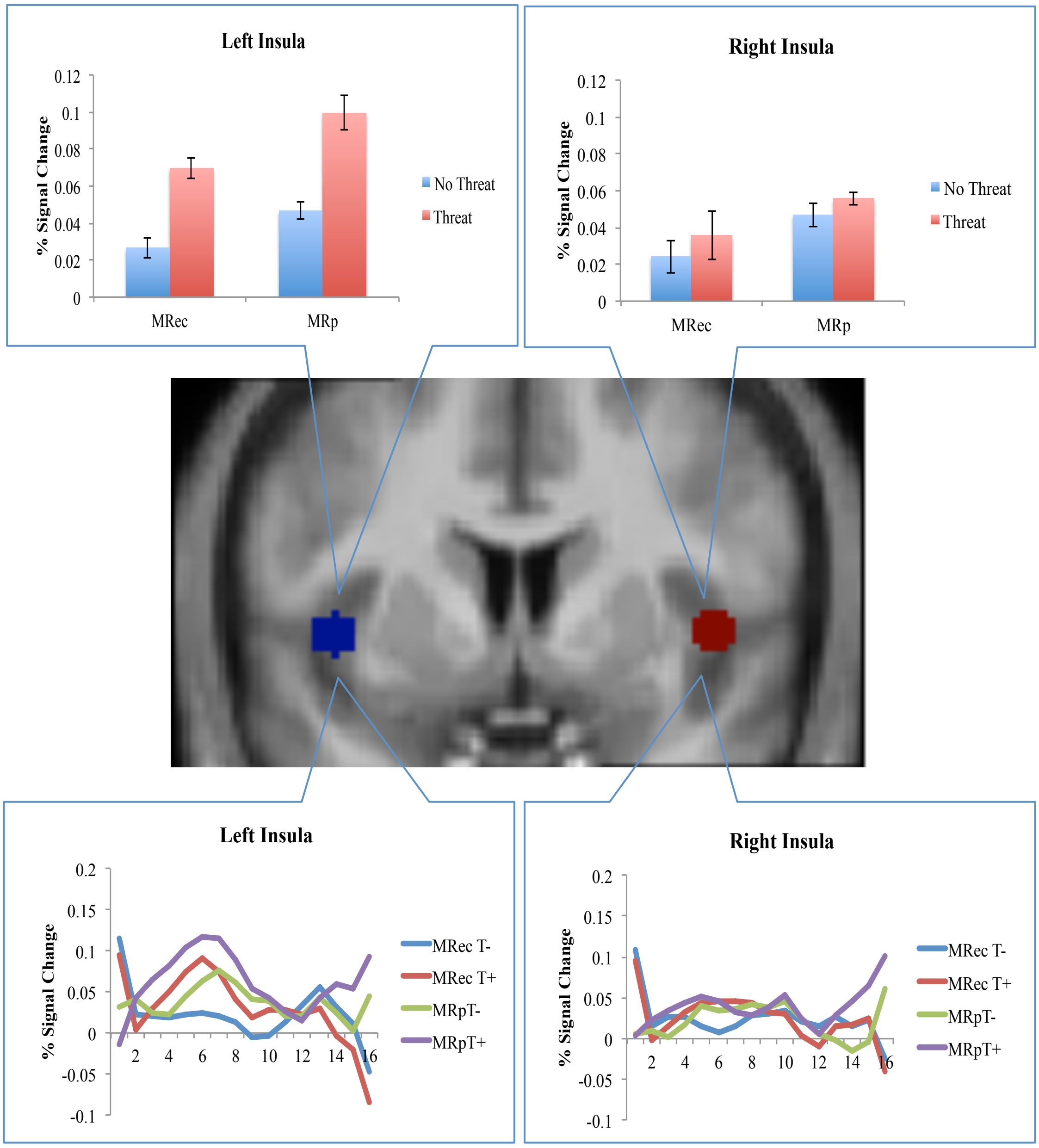

Figure 5.7. Mean peak evoked responses from the Threat Detection Task in the left and right insula as a function of Threat Presence (threat, no threat) and Image Type (MRec, MRp) and the corresponding mean HRF curves.

5.5. Discussion

Soldiers are trained to identify threats and respond with force appropriate to the situation if necessary. Task 1 addresses questions relating to how soldiers make decisions to shoot potentially armed enemy combatants, even when faced with emotionally challenging scenes. As predicted, participants made significantly more false positive errors when faced with MRec images than MRp images. From a signal-detection perspective, participants would ideally make no decisions to shoot when there isn't a threat present, and always make decisions to shoot when presented with a threat regardless of the surrounding distractors (e.g. wounded comrade). However, the bias in the decision to shoot ultimately benefited correct detections, although, this was at the expense of false positive errors. This bias to shoot was irrespective of Image Type.

Participants were quickest to correctly respond when presented with threat present MRp images. Failure to shoot when a threat was present resulted in the slowest reaction times, particularly when presented with MRec images. This is likely due to participants being emotionally aroused by the image distracting the participant from the task. Research examining 'choking under pressure' has showed that heightened state anxiety depletes working memory capacity and serves to reduce performance on tasks that measure cognitive control and focussed attention (Schmeichel, 2007). These findings suggest that heightened affect and arousal act as a 'load' on cognitive resources (Kleider, Parrott, & King, 2009). Thus, impairing a soldier's ability to effectively decide whether to discharge their weapon or not; especially when threatened and experiencing highly arousing negative emotions. This is in keeping with our findings that participants made significantly more conservative decisions to shoot when presented with MRp images than MRec images. This demonstrates their ability to supress their responses when presented with complex scenes, but not when the complex scene also presents emotional challenges.

Our results found that RS (previously associated with high performance under pressure; Perkins, et al., 2007) may be the key to this cognitive control. RS was found to improve participant's ability to discriminate whether a threat is or is not present. However, our results found that this was only the case when presented with MRp images, as RS had no significant influence on ability to detect threats in MRec images. This difference is likely due to the additional cognitive load from emotionally challenging images being placed upon the behavioural activation system (BAS), which is responsible for all goal focused approach behaviour (Gray & McNaughton, 2000).

Previous military research (Simpson, et al., in prep) that underpins the current study identified two dimensions of mental robustness relevant to operational deployments; MRec and MRp. This research supports the previous findings in that although the dimensions are positively correlated with each other; they should be considered two separable dimensions as they correlate with measures of behaviour very differently. While informant ratings of MRec are positively correlated with false positive errors and hits, ratings of MRp are negatively correlated with false positive errors and hits (see *Table 5.4.*). These findings indicated a performance trade-off when presented with emotionally challenging situations during deployment, but not when required to perform in complex high-pressure situations. However, it should be noted that none of these findings achieved a level of significance and therefore the interpretation of these findings should be treated with caution.

Results did however reveal a significant positive relationship between ratings of MRec and number of deployments. This suggests that individuals ability to perform during emotionally challenging situations is learnt through experience. A significant negative relationship between MRp scores and PTSS was also found; indicating that as individual's ability to continue to perform during demanding and complex situations increases, their likelihood of experiencing PTSS decreases. These findings suggest that robustness acts as a resistance resource against PTSS (Swan, Crust, & Allen-Collinson, 2016).

The amygdala plays a causal role in responding to imminent danger (Bach, et al., 2015), mediating the fight-flight response to threat (Davis & Whalen, 2001; Morris, Ohman & Dolan, 1998; Seeley, et al., 2007; Whalen, et al., 1998). In line with previous research (e.g. Phelps, et al., 2001) our findings indicate that when exposed to threat related stimulus, neural activity in the left amygdala increases. A positive percent signal change was also present in non-threatening MRec image. This is likely to be related to the emotionally arousing scene depicted in the stimulus. Our results suggest that the left amygdala's bias towards threats enhanced processing; which resulted in more accurate decisions reducing rates of false positive errors.

Activation in the insula was in keeping with previous research, with increased activation associated with the anticipation of pain (e.g. Ploghaus et al. 1999) and representation of risk (for review, see Kacelnik & Bateson, 1996; Knutson & Bossaerts, 2007; Weber, et al., 2004). Our results found activation in the left and right insula to non-threatening images remained relatively stable. However, participants showed greater percentage signal change in the right insula to threatening images, but a more attenuated percent signal change in the left insula. This same pattern of activation was found in previous research comparing US Navy SEALs with a non-military control group (Paulus, et al., 2010). Paulus (2010) suggested that this pattern of activation represented neural and performance tuning. Rather than personnel expending more effort in general across conditions (like their non-military counterparts), the SEALs conserved processing resources when faced with non-threatening stimulus (Paulus, et al., 2010). This converging evidence suggests the insula is an important region for neurophysiological tuning, and is specifically relevant in emotional and anticipatory processing which allow individuals to be robust in extreme situations. Although the MR-MO was correlated with brain functioning in the direction predicted, none of these findings were found to be significant. Hence, the interpretations of these findings should be treated with caution.

The decision to shoot places a great strain on the brain's cognitive, affective and social functions. While Task 1 examined the cognitive basis for life-or-death decisions, Task 2 looks at the impact of operational deployment on cognition during day-to-day life. More specifically, how 'emotional interference' can compromise the ability to complete tasks requiring cognitive control. The emotional Stroop task is commonly used to examine the impact of PTSD on attentional control in veterans (e.g. Khanna, et al., 2016, 2017). However, little is known about how currently serving personnel are able to maintain attentional control post-deployment. Understanding the mechanisms that personnel employ to maintain cognitive control when faced with emotional interference is particularly important considering the increasing number of military personnel seeking treatment for PTSD since 2007 (MoD, 2016).

Task 2

5.6. Methods

5.6.1 Participants.

See Task 1 for participant demographics (5.3.1). Due to head motion three participants were excluded, the final sample consisted of 22 service personnel (1 RM and 22 Army) for the emotional Stroop task.

5.6.2 Instruments.

The same instruments in Task 1 were used in Task 2.

5.6.3 Materials.

Priming stimulus. Seven minutes of footage from the BBC documentary 'Our War – The Lost Platoon' was utilised as the military priming stimulus and seven minutes of footage from the BBC documentary 'The Perfect Suit' was utilised as the control-priming stimulus. The documentaries were chosen due to formatting similarities and they both depicted all male casts.

Emotional Stroop. An initial pool of 430 operationally relevant words was generated for the Stroop task. Twenty-eight words were identified as being used within the priming footage as such they were also removed resulting in a pool of 402 words. We presented the words to a working group of serving military experts (n = 7 experts in total) who reviewed them based on operational relevance. The review process saw 181 words reported as being military relevant, but not specifically operationally relevant and were thus removed resulting in a pool of 221 words.

The remaining military words were than paired with control words that relate to the control-priming stimulus. The words were matched on first letter, number of letters, number of syllables, and emotional valence. Both military and control words were then presented to a secondary working group of experts, who reviewed them for emotionality and identified words that have shared meaning across both word categories (e.g. flannelette, an issued cloth used to clean the barrel of a rifle and a popular suit fabric). This resulted in 35 words being removed resulting in 186 paired words.

Finally, the reading age of each word was assessed. The average school grade of each word using the Flesch-Kincaid readability calculator indicator tool (Flesch, 2007). The mean school grade for the military words was 10th grade (M = 10.37, SD = 8.10) the equivalent of 14-16 years and the mean school grade for the control words was 9th grade (M = 9.37, SD = 6.31) the equivalent of 14-15 years. An independent *t* test revealed that this difference was not significant; $t(370) = 1.33$, $p = .18$ (see *Table 5.6.* for examples of paired words).

Table 5.6. Examples of word stimuli for the emotional Stroop task.

Operational Words	Reading Age	Control words	Reading Age	No. of Letters	No. of Syllables
Dead	5-7 years	Dart	5-7 years	4	1
Tracer	10-11 years	Tartan	12-14 years	6	2
Unload	12-14 years	Uncool	12-14 years	6	2
Nuclear	14-16 years	Needles	14-16 years	7	2
Platoon	14-16 years	Playboy	14-16 years	7	2

5.6.4 Procedure

See Task 1 for recruitment procedure. Similar to the threat detection task, the emotional Stroop task was also comprised of two runs, with 181 trials within each run. Each trial saw either an operational or control word presented for 1000ms followed by a fixation for 1000ms (see 'C' of *Figure 5.3* for a schematic of a trial). We randomized word order and word colour within each run. Participants were naïve to the existence of different word lists and were instructed to 'name the colour' via button press (Red, Green, Blue, Yellow). They were asked to do this as quickly and as accurately as they could during the 2000ms trial. The first 10 trials and the last 8 trials of each run were presented as fixations and not included in the analysis.

Prior to each run of the Stroop task, participants viewed seven minutes of priming footage either control or military relevant footage (see (D) and (E) of *Figure 5.3* for screen grabs from the footage). The order of the priming footage was counterbalanced across participants. Participants were trained which button on the button box represented which colour during a practice session. This practice session was completed before the first Stroop priming footage (see (A) of *Figure 5.3* for order of experimental design).

5.6.5 Data pre-processing and analysis.

The same pre-processing procedure was used in Task 2 as was used in Task 1.

5.6.6 Behavioural data analysis.

Reaction times in milliseconds (ms) were recorded for every valid trial in which the speed of the response fell within the allotted window (2000ms). Responses faster than 100ms were coded as missing (invalid) data. To create a singular reaction time index we calculated the difference-in-differences (DiD) between the conditions providing us with a reaction time index (RTI). The RTI allow us to examine the effect of measures of individual differences (e.g. PTSS) on reaction times that are not related to the task conditions. The RTI score was calculated with the following transformation: (Military Prime, Military Word – Military Prime, Control Word) – (Control Prime, Military Word – Control Prime Control Word).

5.6.7 Region of interest (ROI) analysis.

The ROI extraction process employed in Study 1 was also used in Study 2. We defined a priori anatomical regions based on previous findings (Amygdala, van Wignen, et al., 2011; AntHC, Rothbaum & Davis, 2003; vmPFC, Khanna, et al., 2017). To do this we identified coordinates related to these regions (see *Table 5.7.*) and used these to define a set of voxels in each participant that comprised their ROI. As in Study 1, 5mm radius spherical ROIs were defined using the MarsBaR ROI toolbox (Brett, et al., 2002). Peak activation clusters for each ROI were generated from the dataset using SPM12, with a threshold of p = 0.001 FW corrected. The time courses for each ROIs were then extracted. This raw time course was then converted into percent signal change for each condition with the following transformation: (condition – fixation)/fixation x 100. The peak activations for each condition trial was then extracted for group-level analyses in SPSS. Repeated measures ANOVAs were used to identify effects of Prime (military, control) and Word (military, control). As in Study 1 a difference-in-differences (DiD) score was calculated for each ROI to allow us to examine the effect of measures of individual difference on brain activation related to the interaction of the task conditions.

Table 5.7. Previously reported anatomical MNI coordinates for the ROIs used in the emotional Stroop task.

	Previously reported coordinates						
	Left			Right			
	x	y	z	x	y	z	Reference
Amygdala	-24	0	-21	21	-1	-22	Papademetris, et al 2006
AntHC	-31	-3	-25	28	-13	-26	Barenese, et al., 2011, 2010
vmPFC	-23	55	4	23	55	7	Papademetris, et al 2006

5.7. Results

5.7.1 Behavioural results.

Reaction Times. The impact of Prime (military, control) and Word (military, control) on participant reaction times was examined. A within-subjects 2 (Prime) X 2 (Word) ANOVA revealed no significant main effect of Prime ($F(1,21)=1.84$, $p=.18$) or Word ($F(1,21)=.64$, $p=.43$) on reaction time. However, there was a significant interaction effect: $F(1,21)=6.42$, $p=.01$. A simple effects analysis revealed a significant difference between Word type when primed with military footage ($p=.008$) but not when primed with control footage ($p=.35$; see *Figure 5.8.*).

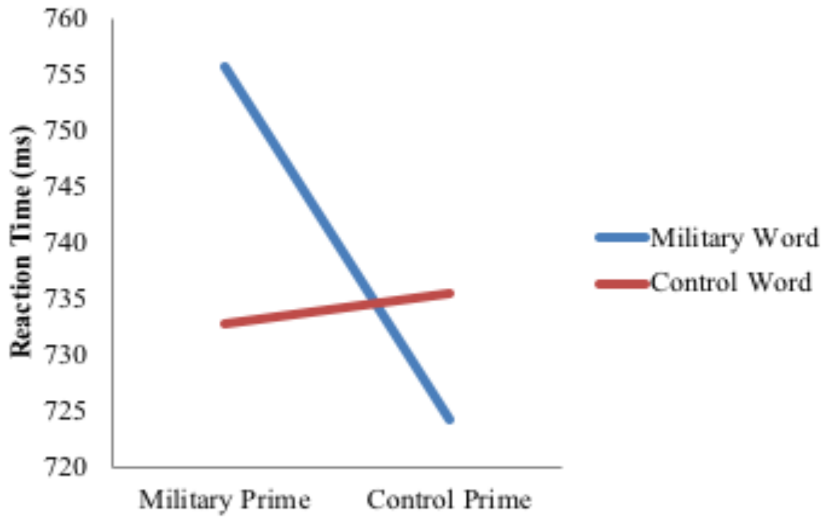

Figure 5.8. Mean reaction times as a function of Prime (military vs. control) and Word (military vs. control).

Measures of individual difference. A correlation analysis was conducted to establish the relationship between reaction times and measures of individual difference associated with military service (e.g. number of deployments), mental health (e.g. PTSS) and performance (e.g. MRp). A number of significant correlations were identified. These included a significant positive correlation between number of deployments and educational attainment (p=.05) and a significant positive correlation between educational attainment and MRec (p=.04). PTSS was found to be significantly correlated with number of deployments (p=.02) and PS (p=.02) and negatively with anxiety (p=.01) and MRp (p=.01). Despite being positively correlated, there was no significant relationship between task performance and rating of MRec and MRp. See *Table 5.8.* for the full correlation matrix.

Table 5.8. Correlation matrix for the emotional Stroop task behavioural and measures of individual difference.

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1 RTI	-								
2 No. Deploy	-.05	-							
3 EduA	.23	**.42***	-						
4 PTSS	-.09	**.49***	.008	-					
5 Depression	.03	-.32	.20	-.31	-				
6 Anxiety	.13	-.13	.35	**-.52***	-.07	-			
7 MRp	.07	.29	.35	**-.50***	-.12	**.39***	-		
8 MRec	.07	**.47***	**.44***	-.14	-.31	.20	**.58***	-	
9 PS	-.08	.07	-.31	**.47***	-.29	**-.41***	**-.38***	**-.41***	-
10 RS	.01	.04	-.19	.22	**.53***	-.29	**-.37***	**-.44***	.06

NB: n=22 for all variables. RTI= Reaction Time Index, No. Deploy= Number of Deployments, EduA= Educational Attainment, PTSS= Post traumatic stress symptoms, MRp= Mental robustness pressured performance, MRec= Mental robustness emotional challenges, PS= Punishment Sensitivity, RS= Reward Sensitivity. * = p<.05.

5.7.2 Neuroimaging Results

Our ability to regulate our emotional responses is an important part of normal social behaviour. The amygdala and hippocampus are essential in emotional learning and memory and are involved in the assessment of threat related stimuli (Davis & Whalen, 2001; Morris, Ohman & Dolan, 1998; Seeley, et al., 2007; Whalen, et al., 1998). The vmPFC is involved in executive function and decision-making, particularly the regulation of emotional conflict (Etkin, et al., 2011). These three regions have been identified in previous research which has employed the emotional Stroop task with veterans, in relation to task performance. Task performance is associated with emotional regulation and attention allocation (Khanna, et al., 2017), and therefore, these three regions were chosen as ROIs for Task 2.

To examine the effect of measures of individual differences (e.g. PTSS) on brain activation which are not related to the task conditions; a correlation analysis was conducted. Results indicated a significant negative correlation between activity in the right amygdala and the RTI (p=.007), as well as between activity in the left antHC and RTI (p=.01). These results indicate that as activity in the right amygdala and left antHC increases, reaction times decrease. For a full break-down of the results see *Table 5.9*.

Table 5.9. Emotional Stroop task correlation results between measures of individual difference and DiD activity for each ROI.

	Left Amygdala	Right Amygdala	Left AntHC	Right AntHC	Left vmPFC	Right vmPFC
1 RTI	-.16	**-.56****	**-.50***	-.08	-.18	-.25
2 No. Deploy	-.18	.04	-.01	-.06	-.11	.29
3 EduA	-.13	.27	-.04	-.13	-.22	.06
4 PTSS	-.06	.13	-.09	-.12	-.22	-.18
5 Depression	.35	.27	.12	-.003	.003	-.17
6 Anxiety	-.36	-.16	-.19	-.21	.07	.33
7 MRp	-.02	-.01	.18	.08	.26	.39
8 MRec	-.06	.09	.03	.02	-.06	.33
9 PS	.11	-.22	-.31	-.17	-.05	.05
10 RS	.23	.03	-.13	-.03	.02	-.13

NB: n=22 for all variables. RTI= Reaction Time Index, No. Deploy= Number of Deployments, EduA= Educational Attainment, PTSS= Post traumatic stress symptoms, MRp= Mental robustness pressured performance, MRec= Mental robustness emotional challenges, PS= Punishment Sensitivity, RS= Reward Sensitivity. ** = p<.01, * = p<.05.

The impact of Prime (military, control) and Word (military, control) on the mean of peak HRF percent signal change in each ROI was also examined. A within-subjects 2 (Prime) x 2 (Word) ANOVA revealed a main effect of Prime ($F(1,21)=4.27$, $p=.05$). To explore the nature of the main effect a simple effects analysis examining the difference between Word (military, control) within Prime was conducted. Results revealed no significant difference between military and control words when primed with military footage ($p=.21$) or when primed with control footage ($p=.11$). Results indicated no main effect of Word ($F(1,21)=.001$, $p=.97$) and no interaction effect ($F(1,21)=.24$, $p=.62$; see *Figure 5.9.*).

The impact of Prime (military, control) and Word (military, control) on percent signal change in the right amygdala was assessed. A within subjects 2 (Prime) x 2 (Word) ANOVA revealed no main effect of Prime ($F(1,21)=.78$, $p=.38$) or Word ($F(1,21)=.01$, $p=.90$) and no interaction effect ($F(1,21)=.41$, $p=.52$; see *Figure 5.9.*).

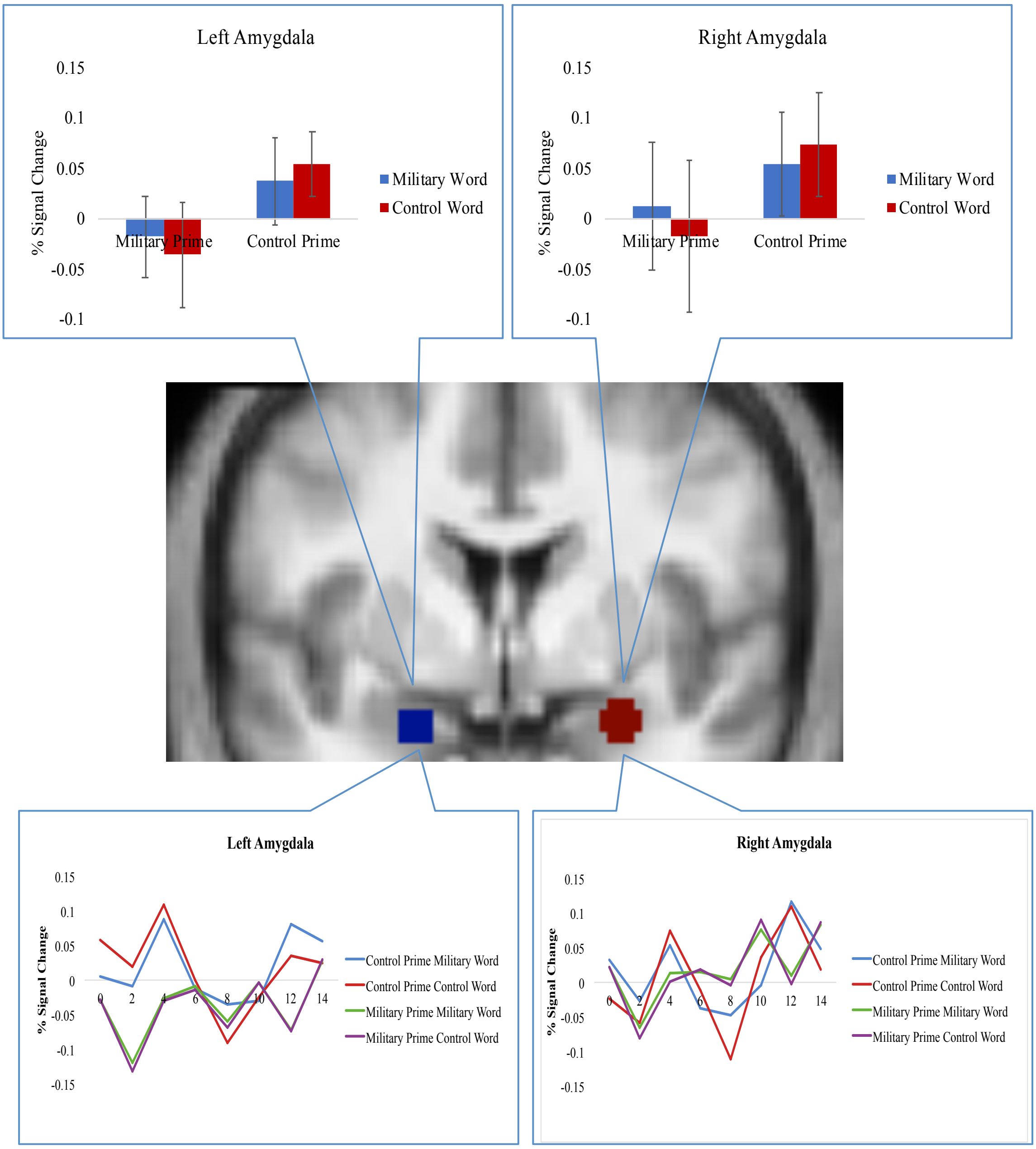

Figure 5.9. Mean peak evoked responses from the emotional Stroop task in the left and right amygdala as a function of Prime (military, control) and Word (Military, Control) and corresponding mean HRF curves.

The impact of Prime (military, control) and Word (military, control) on percent signal change in the left antHC was assessed. A within subjects 2 (Prime) x 2 (Word) ANOVA revealed no main effect of Prime ($F(1,21)=.48$, $p=.49$) or Word ($F(1,21)=.03$, $p=.84$) and no interaction effect ($F(1,21)=2.00$, $p=.17$; see *Figure 5.10.*).

In the right antHC a within subjects 2 (Prime) x 2 (Word) ANOVA revealed no main effect of Prime ($F(1,21)=.06$, $p=.80$) or Word ($F(1,21)=.02$, $p=.88$) and no interaction effect ($F(1,21)=.11$, $p=.74$; see *Figure 5.10.*).

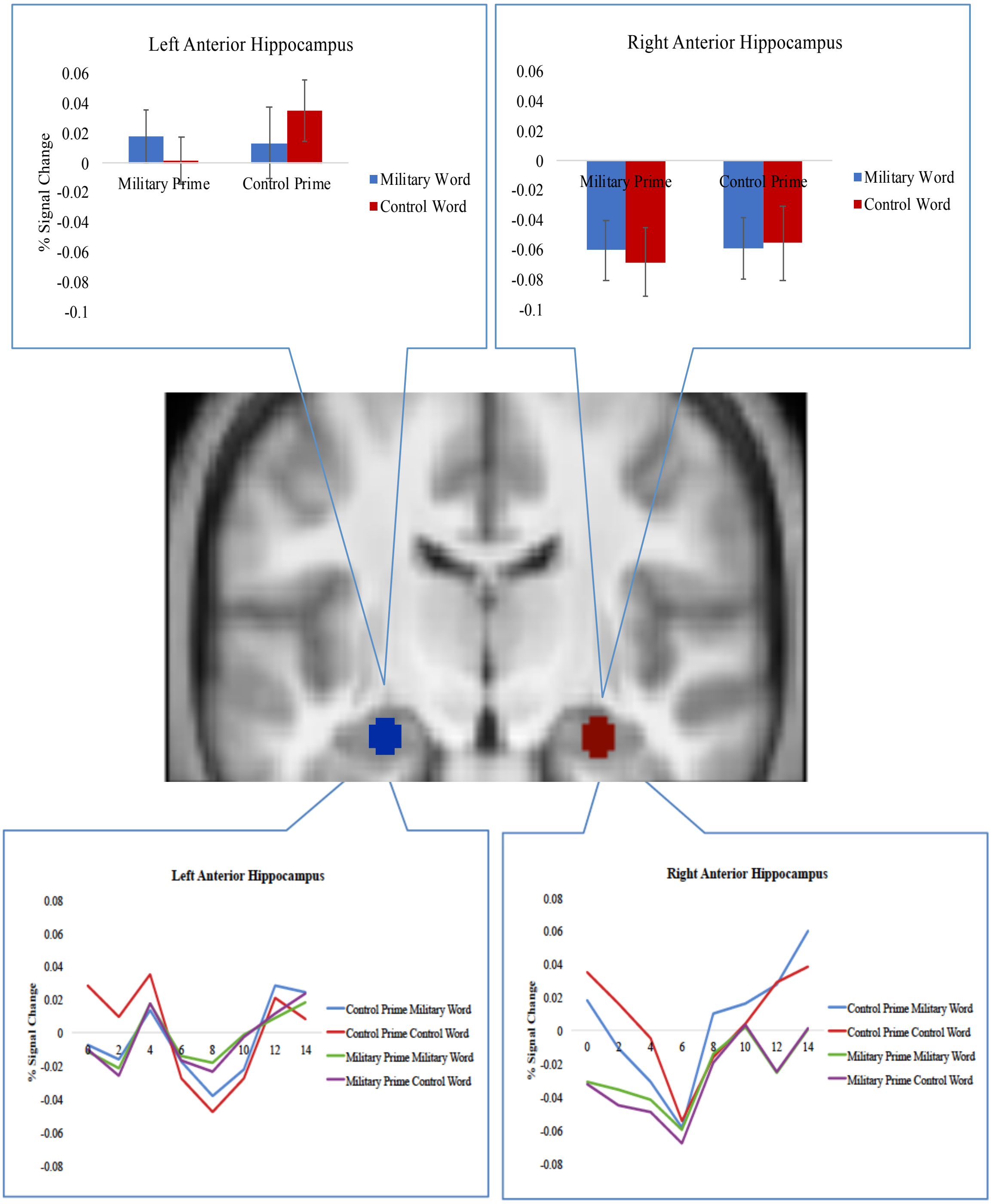

Figure 5.10. Mean peak evoked responses from the emotional Stroop task in the left and right anterior hippocampus as a function of Prime (military, control) and Word (Military, Control) and corresponding mean HRF curves.

The impact of Prime (military, control) and word (military, control) on percent signal change in the left vmPFC were examined. A within subjects 2 (Prime) x 2 (Word) ANOVA revealed no main effect of Prime ($F(1,21)=.17$, $p=.68$) or Word ($F(1,21)=3.04$, $p=.09$) and no interaction effect ($F(1,21)=.16$, $p=.69$; see *Figure 5.11.*).

In the right vmPFC a within subjects 2 (Prime) x 2 (Word) ANOVA revealed no main effect of Prime ($F(1,21)=.82$, $p=.37$) or Word ($F(1,21)=.10$, $p=.74$) and no interaction effect ($F(1,21)=.07$, $p=.78$; see *Figure 5.11.*).

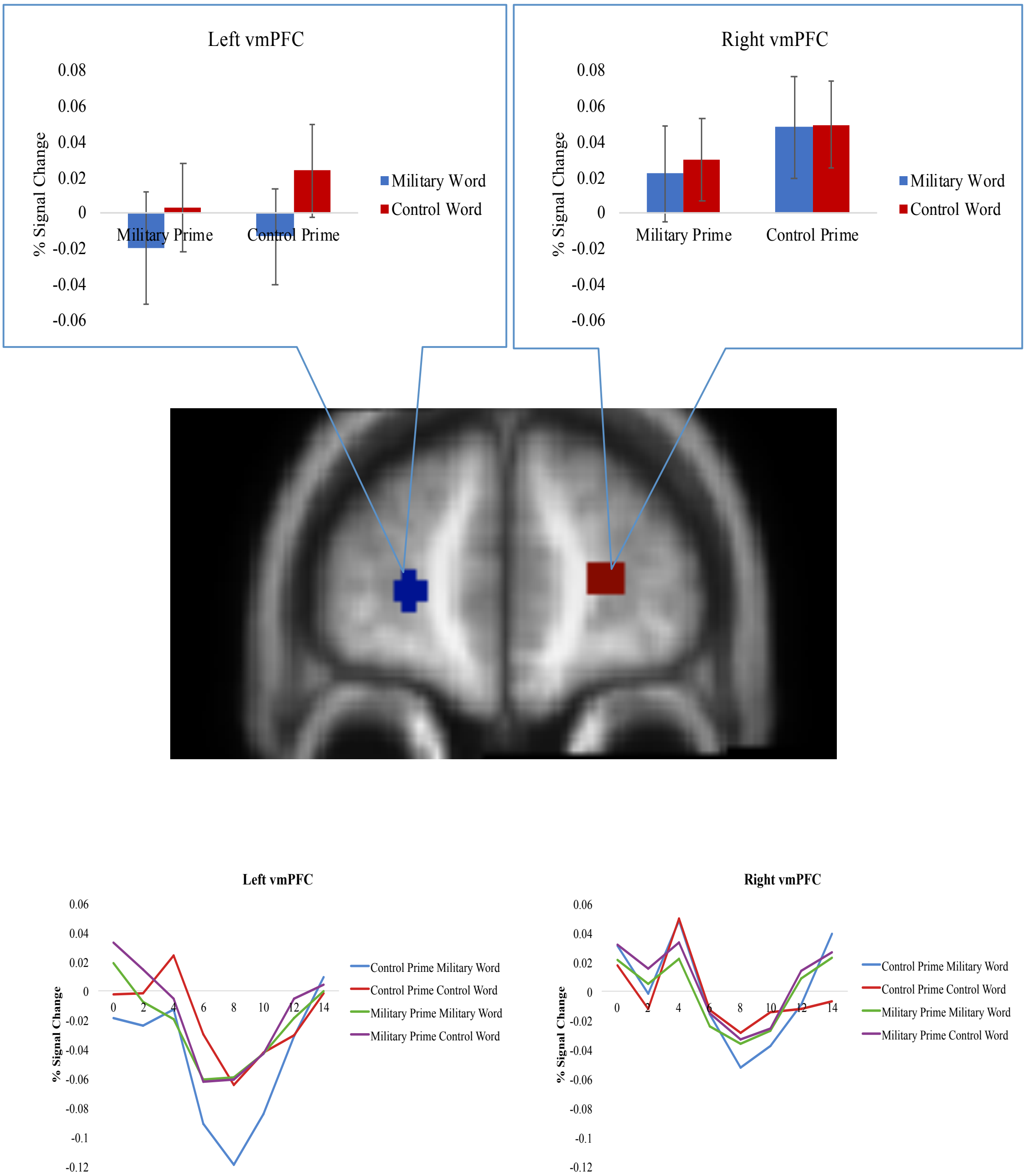

Figure 5.11. Mean peak evoked responses from the emotional Stroop task in the left and right vmPFC as a function of Prime (military, control) and Word (Military, Control) and corresponding mean HRF curves.

5.8. Discussion

When soldiers return from operational deployment they are expected to integrate back into society and complete simple day-to-day tasks. However, many psychological disorders, including PTSD are associated with aberrant attention allocation patterns and altered stimulus representation across brain regions (Blair, et al., 2013). Task 2 addresses questions relating to how soldiers make simple decisions when faced with reminders of combat. In line with previous research, Khanna et al (2017), conducted emotional Stroop research, which compared veterans with and without PTSD, and, found participants showed longer colour naming latencies for combat related words compared with control words. However, in contrast with previous research, we found a negative relationship between reaction times and PTSS, indicating that PTSS actually improved task performance.

Reminders of traumatic experiences can, for some individuals, trigger hyper-arousal, resulting in increased activation in the amygdala (Luo, et al., 2010; Todd, et al., 2015). However, othersmay experience emotional numbing/avoidance, resulting in decreased activation in the amygdala (Khanna, et al., 2017). Our results found a main effect of prime, with reduced activation in the left amygdala when primed with military footage. These findings suggest that the reminder of combat followed by a task requiring the soldiers to ignore the emotional relevance of the stimulus, saw participants employ emotional numbing/avoidance as a strategy to aid performance. Research with experienced climbers suggests that individuals who place their emotions on hold after experiencing a PTE go on to report negative consequences at a later date (Swann, et al., 2016). Considering this, while emotional numbing may aid performance in the short term, this approach is likely to have long term negative health consequences for soldiers.

Examination of the DiD activation revealed a significant negative relationship between task performance and activation in the right amygdala. In line with previous research, these findings indicate that regardless of the stimulus presented, activation in the right amygdala hindered performance on the emotional Stroop task (Khanna, et al., 2017). It could be argued that the novelty of the control footage and control words increased activation in the amygdala, with soldiers taking longer to identify them as non-threatening; this could be related to attentional perseverance to threats. However, it is unlikely considering the behavioural results in which PTSS were found to improve performance, and ratings of MRec and MRp had no significant impact on task performance.

PTSD has been associated with relatively less activity within emotional regulation areas such as the hippocampus (Khanna, et al., 2017). Our findings demonstrate a negative percent signal change in brain activity in the right antHC, but increased activity in the left antHC. Research comparing veterans with and without PTSD found patients with PTSD to display reduced activation in the hippocampus when processing combat-related words as opposed to neutral words (Khanna, et al., 2017). However, while previous research reports that reduced activation is indicative of reduced emotional control and poorer task performance; our results found that increased activity in the antHC significantly impedes task performance, regardless of stimulus condition.

This lack of activation in the limbic system was paired with increased activation in the vmPFC. Research examining conflict monitoring in healthy participants found that the engagement of the PFC biased behaviour toward a goal-relevant response, and suppressed task irrelevant information (Kerns, et al., 2004). Our findings suggest hemispheric differences in attentional control, with increased activation in the right vmPFC across all conditions, but only increased activation in the left vmPFC when presented with control words. Research has shown that activation in the vmPFC is context dependent (Kalisch, et al., 2006), with responses scaled differently to various stimuli in the environment depending on their positive or safety properties (Schiller & Delgado, 2010). Previous research also indicates that reduced activity in the vmPFC is associated with symptoms of emotional numbing/avoidance in individuals diagnosed with PTSD (Rougemont-Bücking, et al., 2011). Considering this, our results suggest that the reduced activation in the left vmPFC may be associated with emotional/numbing strategies, employed by personnel to aid task performance.

5.9. General discussion

The present research examined the neurocognitive underpinnings of mental robustness relevant to operational deployment, as well as how these experiences may influence attention allocation post-deployment. Both Task 1 and Task 2 assessed attention allocation and decision making under pressure. While Task 1 required participants to attend to emotional aspects of stimuli, Task 2 required participants to attend to the non-emotional aspects of the stimuli. By comparing participants performance across these tasks, we are able to gain an understanding of how individuals are able to perform during deployment and during post-deployment. This then enabled us to identify what individual differences participants employ in order to aid task performance. Most notably, our findings suggest soldiers were able to positively utilise symptoms of PTSD to improve task performance. Specifically, oscillating between hypervigilance to improve performance in Task 1 and emotional numbing/avoidance to improve performance in Task 2. These findings are suggestive of a curvilinear (inverted-U) relationship between PTSS and performance with the psychological benefits of deployment counteracting the psychological liabilities (for a review see, Linley & Joseph, 2004).

Our findings provide further evidence that MRec and MRp are two separate dimensions of mental robustness relevant to operational deployments. However, no evidence was found to support the hypotheses that positive ratings of MRec and MRp would predict task performance. In addition, neither MRec nor MRp were found to predict brain region functioning on this occasion. Considering the rates of PTSS reported by participants, it could be argued that these participants are not truly robust. Further examination of the distribution of scores indicates that there is very little variance in the MR-MO data; with all participants being rated in the top half of the measurement scale, and that mental robustness (as measured by the MR-MO) has very little impact on performance in the threat detection task (see Figure 5.12). To truly understand what these findings mean in relation to robustness and performance, further research should be conducted. This would allow us to clarify if high rates of robustness, as reported here, are a product of military training, or a product of bias by the single source informant.

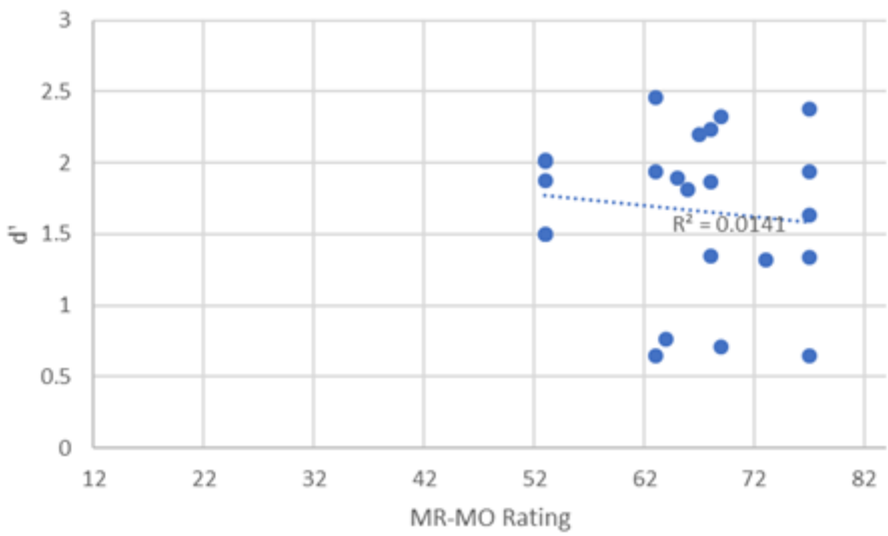

Figure 5.12 Informant rating of mental robustness in relation to performance (d') on the threat detection task.

Our research indicates that, at present, our soldiers are learning to deal with emotionally challenging situations through experience. For some, this will result in devastating consequences associated with false positive errors when discharging their weapons. It is hoped that this research will inform pre-deployment training with more emphasis to be placed on training soldiers for the emotional challenges that war presents.

The sample size within this study is worthy of note. While the sample size is typical of fMRI research, it is considered small for individual differences research (Dubois & Adolphs, 2016). MRI safety restrictions meant that a high proportion of willing volunteers were unable to take part due to shrapnel injuries. Furthermore, a unit of Royal Marines was deployed un-expectedly before we were able to collect data from them. If given time, we would have been able to collect data from a larger sample however, it is still unlikely that we would have been able to achieve the ‘gold standard’ of 100 participants (Dubois & Adolphs, 2016).

Despite this, it is hoped that this research will result in a deeper understanding of the critical factors required for optimal military performance during deployment. Understanding what accounts for robustness in military personnel, and how soldiers perform to a high standard has practical implications for the military and can inform pre-deployment training and post-deployment re-integration procedures.

Chapter 6

General Discussion

The goal of this thesis was ultimately to further our understanding of the role of mental robustness in the military. Specifically, I investigated how soldiers are able to continue to perform during adversity and when presented with emotional challenges associated with combat. I also investigated if this ability to perform came at a cost to their mental health post-deployment. In the following I provide a short summary of the empirical findings from the thesis, followed by a discussion of the implications of the research and recommendations for the future. Finally, I will examine the strengths and limitations of this research.

6.1. Summary of main findings

Chapter 3 – Study 1 and 2. A soldier's ability to continue to perform when presented with a life or death situation is not well understood. Military literature to date has focused on either an individual's ability to make decisions under pressure, typically during training and selection (Arthur, et al., 2015; Fitzwater, et al., 2017; Simpson, et al., 2006) or has examined the emotional challenges of combat focussing on the psychological cost of experiencing such challenges (Fear, et al., 2010; Hanwella & de Silva, 2012; Hoge, et al., 2004; Killgore, et al., 2008; Osório, 2013, 2017). Taking this previous research into account we developed an informant rated, operationally relevant, measure of mental robustness. The measure captured a soldier's ability to make decisions under pressure (MRp) and perform even when faced with emotional challenges (MRec) as two separable dimensions. Study 1 focused on item development and the structural validity of the measure of Mental Robustness for Military Operations (MR-MO) in a sample of Royal Marine Commandos. Bayesian structural equation modelling (BSEM) analyses revealed that, following item removal, a 12-item measure provided an acceptable model fit.

Study 2 utilised a sample of Army Infantry soldiers and provided confirmation of the two-factor structure of the MR-MO, again via a BSEM approach. Initial evidence of construct validity of the measure was also found with combat exposure (considered a risk factor) positively impacting informants' ratings of MRec and education (considered a protective factor) positively impacting informants ratings of MRp. Despite the influence of these covariates, the MR-MO was still able to discriminate between the two service groups indicating good construct validity. Overall, the MR-MO displays sound psychometric properties and is the first multidimensional measure of robustness that is relevant to operational deployment.

Chapter 5 – Study 3. In a bid to understand how individuals are able to perform during combat when faced with challenges associated with MRp and MRec we combined behavioural and functional imaging with psychometric measures. In this third study we employed two tasks; Task 1 was a threat detection task which assessed participants ability to identify threats in operationally relevant images. The images were categorised as either MRp relevant (images of complex operational scenes) or MRec relevant (images of emotionally challenging operational scenes). Results indicated that emotionally challenging images resulted in a bias to shoot regardless of whether a threat was present or not. However, there was no significant negative relationship between an individual's bias to shoot and informant ratings of MRec and MRp. Reward sensitivity (RS) was found to improve participants ability to discriminate between threat and non-threatening MRp images but not MRec images.

Increased activation in the amygdala was associated with increased frequency of hits and reduced false positive errors. Activation in the insula showed greater percentage signal change in the right insula to threatening images, but a more attenuated percent signal change in the left insula. Previous military research suggested that this pattern of activation represented neural and performance tuning (Paulus, et al., 2010).

Task 2 employed an emotional Stroop task, preceded by a priming influence. This approach allowed us to investigate interference effects of combat relevant words on cognitive processing. Cognitive conflict can arise due to ‘emotional interference’ and can compromise one’s ability to complete tasks requiring cognitive control. A priming influence was employed prior to participants completing the task to enhance the magnitude of the semantic meaning of the combat relevant words. More specifically, results found that participants showed longer colour naming latencies for combat related words compared with control words when primed with military footage. However, when primed with control footage participants showed longer colour naming latencies for control words. In contrast with previous research we found a negative correlation between reaction times and PTSS. These findings indicate that PTSS actually improved soldier’s performance on the emotional Stroop task allowing individuals to supress emotional arousal associated with military words.

Our brain imaging results support these findings with a negative relationship between PTSS and increased activity in the amygdala and antHC regardless of task condition. In line with previous research (Khanna, et al., 2017) performance was predicted by reduced activity in these regions. This lack of activation in the limbic system was paired with increased activation in the vmPFC. More specifically, in the left vmPFC increased activity was associated with control words while reduced activity was associated with military words. Previous research suggests that reduced activity in the vmPFC is associated with symptoms of emotional numbing/avoidance (Rougemont-Bücking, et al., 2011).

6.2. Research implications

6.2.1 Theoretical implications.

A key concept to arise from this thesis concerns the discrimination between two dimensions of mental robustness relevant to operational deployment. This thesis provides evidence across three studies that MRp and MRec are two separable dimensions of mental robustness. Although the two subscales of the MR-MO are highly correlated, this high correlation is likely an artefact of measurement as both components of MR share a common need to effectively handle negative or challenging contexts or events (e.g. pressure, trauma), yet are conceptually distinct. In other domains of psychology, it is not uncommon for conceptually separate factors to be highly correlated. For example, work in Self-Determination Theory has reported strong correlations between subscales by a number of researchers (e.g. Markland & Tobin, 2010; Niven & Markland, 2016; Vlachopoulos, et al., 2010). Previous findings suggest that this correlation between subscales is context dependent and, in some circumstances, the subscales are complimentary of one another (Hagger, et al., 2006).

Further, evidence from Study 3 provides support for the differentiation between MRp and MRec. Indeed, MRp and MRec predict divergent outcomes; MRp is associated with measures of task performance while MRec is associated with measures of mental health. For example, within Task 1 increased activation in the amygdala was associated with increased task performance. Our results from Task 1 showed a stronger positive correlation between MRp ratings and activity in the right amygdala than MRec ratings. However, in Task 2 reduced activation in the amygdala was associated with increased performance. Our results from Task 2 showed increased activity in the right amygdala to be positively correlated with ratings of MRec but negatively correlated with ratings of MRp.

These findings provide preliminary neurocognitive evidence that MRp predicts a soldier's ability to perform under pressure while MRec predicts a soldier's ability to deal with emotional challenges associated with combat. However, in Task 2 results suggest that the additional cognitive load associated with the processing of emotionally challenging stimulus came at the cost of task performance. These findings provide further evidence of neurocognitive tuning in military personnel.

Applying reinforcement sensitivity theory to understand why individuals differ in their responses in performance domains is an important step forward that has received limited consideration in the existing literature. A theoretical issue revealed in this thesis relates to the role of threat detection and reward sensitivity and the ability to explain behavioural output and emotions with respect to underlying neuropsychological networks (McNaughton, DeYoung, & Corr, 2016). While reward sensitivity (RS) appears to significantly positively influence a soldier's ability to successfully detect threats in complex military scenes it was not as effective when presented with emotionally challenging scenes. These findings suggest that RS may only be adaptive in certain military contexts. This difference is likely due to the additional cognitive load emotional challenging scenes placed on the behavioural activation system (BAS) which is responsible for all goal focused approach behaviour (Gray & McNaughton, 2000).

A significant positive correlation between RS and a soldier's increased ability to detect threat was also found (see *Figure 6.2.*). Our findings support previous research with military cadets which also found RS to be highly correlated with performance during a tactical judgment scenario (Perkins, et al., 2007). Their findings also found punishment sensitivity (PS) to be a significant predictor of poor task performance (Perkins, et al., 2007). Our results did not find a negative correlation between PS and task performance (d') but the positive correlation was only marginal indicating that RS is a far better predictor of task performance than PS for military personnel.

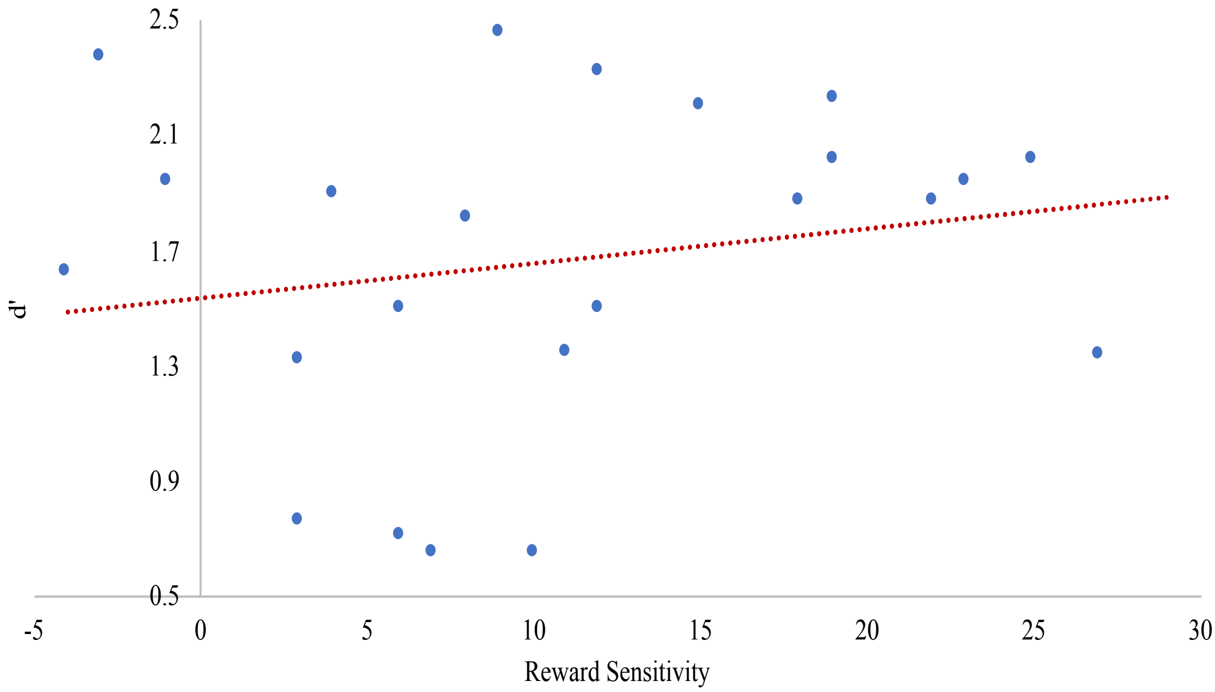

Figure 6.2. Significant positive relationship between task performance and reward sensitivity in the threat detection task.

In contrast, research with athletes (e.g. Hardy, et al., 2013; Beattie, Alqallaf & Hardy, 2017) found that the combination of high PS combined with low RS was associated with improved performance and increased ratings of mental robustness. The disparity in findings between military and sport research may be related to what constitutes a reward to athletes (winning a race) compared to soldiers (staying alive). In fact, for a soldier in combat a reward may also be the absence of a punishment (death). Further research with military personnel is required to untangle if it is reward or the absence of punishment that is driving performance in soldiers during combat, one would predict it to be a combination of both. For example, a threat detection task which sees soldier's performance tied to a 'monetary system' in which soldiers start off with a pot of money that would be donated to a military charity of their choice. Missing threats or false alarms would result in a financial loss while hits and correct detections would result in financial gain for their charity.

6.2.2 Applied implications.

The elicitation of intense emotional states and experience of uncontrolled arousal under battle conditions can undermine critical mental resources and processes that soldiers require to execute their responsibilities (Harris, Salas, & Stanton, 2012). Our research suggests that while soldiers are being effectively prepared to perform under pressure in combat environments they may not be adequately prepared for the emotional challenge war presents. Our results indicate a significant positive correlation between ratings of MRec and number of operational deployments. These findings suggest that a soldier's ability to deal with the emotional challenges of combat is at present gained through operational experience. This ability to deal with heightened affect and arousal specifically relating to emotionally challenging stimulus predicted task performance. Our results suggest that to perform effectively in both tasks soldiers were able to positively utilise symptoms of PTSD. To do this they oscillating between hypervigilance to improve performance in Task 1 and emotional numbing/avoidance to improve performance in Task 2. These findings are suggestive of a curvilinear (inverted-U) relationship between PTSS and performance with the psychological benefits of deployment counteracting the psychological liabilities (for a review see, Linley & Joseph, 2004). To assess if these assumptions are true future research would benefit from also measuring emotional numbing and hypervigilance specifically. Avoidance-numbing and hyperarousal symptoms could be measured using the Clinical Administered PTSD Scale (CAPS-5). This scale is composed of 30 items measuring three symptom types (1) re-experiencing, (2) avoidance-numbing and (3) hyperarousal. In addition to using this scale physiological data could be collected as a possible alternative to fMRI when looking to understand the impact of emotional numbing on task performance. Previous research employing the CAPS-2 scale has revealed a significant correlation between lower urinary cortisol levels and avoidance-numbing symptoms (Mason, et al., 2001). Measuring cortisol levels would provide an indication that an individual's memory formation may have been impacted resulting in an emotional numbing response.

These findings demonstrate the essential role that mental processes play in the effectiveness and wellbeing of military personnel. Training personnel to explicitly deal with the emotional challenges of combat is nothing new. Military medics are trained to not only cope with the emotional burdens associated with maintaining the health and well-being of their fellow soldier's but are also trained to deal with their own potential life-threatening situation resulting from combat operations. Previous research found that rates of PTSD to be lower among medics than ground combat troops (Pitts, et al., 2014; Thomas et al., 2010). It could be argued that this difference in rates of PTSD was associated with combat experiences and the impact of killing (Grossman, 1996; Litz et al., 2009; MacNair, 2002) rather than witnessing killing. However, while this is one possible explanation it is likely that being trained to deal with the emotional challenges of war had to some degree a positive influence on levels of PTSS reported by military medics.

Our findings indicate that front line troops are better at identifying threats when presented with MRp relevant scenarios. These findings suggest that there may be a gap in pre-deployment training for front line troops relating to their ability to deal with the emotional challenges combat can present. Considering previous research (Pitts, et al., 2014; Thomas et al., 2010) training soldiers (like medics) to deal with the emotional burdens of combat could strengthen the negative relationship between MRec and PTSS. In turn this strengthened relationship could result in a diminished relationship between MRec and number of deployments. This could provide preliminary evidence that it is training that enables soldiers to perform effectively during deployment not the experience of combat itself.

6.3. Strengths and limitations

This research is the first to directly measure soldier's ability to attend to emotionally challenging aspects of stimuli and measure the same soldier's ability to complete a task that requires them to attend to non-emotional aspects of the stimuli. Previous research has examined either a soldier's ability to detect threat using operationally irrelevant stimuli (e.g., Paulus, et al., 2009, 2010; Simmons, et al., 2012; van Wingen, et al., 2011) or attentional bias using an emotional Stroop task (e.g., Khanna, et al., 2016, 2017; Todd, et al., 2015). However, for soldiers, the ability to successfully complete both these tasks are required. While their role in the military requires them to be excellent at detecting threats and making accurate decisions, to be able to function successfully outside their military role soldiers need to be able to disengage these attentional resources. Failure to do so results in a load on cognitive resources with soldiers seeing a world populated with traumatic cues which perpetuates the effects of trauma (Todd, et al., 2015).

Improving on the previous mental robustness measurement research (e.g. Clough, et al., 2007; Gucciardi & Gordon, 2009; Middleton, et al., 2004) we employed an informant rating approach. Informant reports tend to have greater internal consistency than self-reports as they are free from certain self-report biases (Balsis, Cooper, & Oltmanns, 2015). Therefore, utilising an informant approach allowed us to circumvent some of the social desirability issues associated with self-reporting (see Hardy et al., 2013) which is particularly prominent in the case of mental robustness (see Roberts & Woodman, 2015). Although informant-rated measures are free from social desirability bias they are not necessarily free from other types of bias. Military populations are often proud of the unit they serve in and may not want to tarnish its reputation by reporting that an individual has not performed well during an operational deployment. Considering this, future research should take steps to control for informant biases associated with esprit de corps. This could be achieved by collecting data from more than one informant. For example, Section Commanders, Officer Commanding and peers could be recruited as informants. A 360-degree reporting approach is sometimes used in the military and could offer an alternative to a triangulation approach. It should be noted that to be able to collect data from more than one informant it is recommended that researchers access soldiers during the post-deployment phase. It is often the case that personnel disperse on postings or begin resettlement, a phase resulting in premature voluntary release on return from operational deployment.

To ensure intuitive interpretations of the measurement development data we employed a BSEM approach to assess structural validity. This approach allowed us to more appropriately reflect the reality of small correlations and cross loadings between items and factors, which would not have been possible if we had employed a maximum likelihood CFA approach. However, the analysis failed to take into account the multi-level nature of the data. Currently, the model fit statistics used by MPlus for Bayesian SEM are not available for multilevel models. Thus, we were unable to fully examine the factorial validity and theoretical grounding of the MR-MO as a multi-level measure at this time. With advances in programming capabilities assessing the multidimensional nature of the measure will be important.

The biggest limitation to Study 3 is sample size. The typical sample size for fMRI studies is 15-30 participants. However, it is recommended that this number be scaled up (to

N>100) for individual differences research (Dubois & Adolphs, 2016). Despite our best efforts we were only able to recruit 25 participants for Study 3. This was primarily related to MRI safety restrictions as a high proportion of volunteers for the study were unable to take part due to shrapnel injuries obtained during previous deployments. A number of volunteers (approximately 10) were also deployed overseas at short notice before we were able to collect data from them. Given more time we would have been able to collect data from a larger participant pool. However, with a specialist population such as the serving military the 'gold standard' of 100 participants is not a realistic standard to achieve.

It should also be highlighted that the sample of participants in the research is not representative of the wider regular military population as we only recruited males who had deployed in ground close combat roles in the last five years. We specifically chose to recruit personnel from infantry units as they are at the highest risk of exposure to potentially traumatic events (PTE) and at the greatest risk of experiencing PTSD (Hoge, et al., 2007; Fear, et al., 2010; Van Winkle & Safer, 2011). This gave us the best possible chance of revealing how soldiers who had experienced challenging deployments perform during combat and post-deployment relevant tasks.

6.4. Future directions

Given this thesis is the first study to assess both operational performance and post deployment performance with the same sample using a cross-sectional design, replication of Study 3 with frontline fighting troops is recommended. A possible improvement that could be made would be to use dynamic stimuli in the threat detection task rather than static stimuli. Close combat video-clips captured with a helmet-mounted camera could be used to simulate context, semantics and emotions of a real operational enviroment. Previous research by Cosic, et al., (2012) successfully used real-life combat video clips to assess whole brain activity in experience military personnel. There results found increased overall activity in mission-ready soldiers compared to novice soldiers, particularly in the pre-motor and prefrontal cortex when viewing the videos. These results suggest that mission-ready soldiers actively viewed the footage conceiving possible responses while novice soldiers passively viewed the footage. However, it is unclear if the difference would have translated into a behavioural advantage in mission ready soldiers or if the increased activation was purely due to the relevance of the video content. Irrespective of the findings the study shows that dynamic operational footage can be successfully used with military populations. This recommendation is suggested with caution as head motion during the Stroop priming videos was high and could therefore not be analysed using the ISC analysis technique described in Chapter 4. The addition of eye tracking during fMRI based free viewing tasks using military combat footage is also recommended. This would provide more control allowing researches to identify with a greater degree of certainty exactly what the participant was looking at during neural activation peaks.

If the replication study produces findings consistent with the findings in this thesis then it is recommended that a larger scale study be conducted employing a longitudinal design. Assessing soldiers before, immediately after deployment and at approximately six months post-deployment would allow us to better understand the consequences of operational deployment and its long-term impact on behaviour and on brain systems.

Training interventions that aim to improve an individual's ability to cope with the emotional challenges combat can present could be implemented. This research could examine group differences in task performance between soldiers who do not receive training and soldiers who do. This approach would also allow us the opportunity to understand if training for the emotional challenges of war could potentially act as a resistance resource; reducing soldiers risk of experiencing PTSS that negatively impacts their operational effectiveness and ability to function during post-deployment.

The time, cost and expertise required to replicate the research featured in this thesis are not insignificant. As noted earlier, recruiting operationally fit military personnel who are constantly on the move between training and deploying and who are still serving with the commander they deployed with is no mean feat. However, the potential implications of these findings likely far out way the time and cost involved.

6.5. Conclusion

These findings are important not only to military performance research but also for research examining the negative health consequences of operational deployment. This study may also hold practical significance for military training in terms of helping highly motivated individuals overcome obstacles relating to the emotional challenges of war enabling them to perform to the best of their ability. It is with optimism that I hope the empirical evidence and theoretical considerations within this thesis can contribute towards a greater understanding of the cognitive processes employed during combat and the long-term consequences of such processes.

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Appendix A

8.1. Feedback on MR-MO items from military steering group.

Feed back from a Major General
The 16 items are all germane. The time frame will be key and those who have served in Afghanistan since 2006 will all be able to answer those questions; 2008-9 being particularly bad years for casualties so a 5-year limit might be too narrow.

Feed back from Lt. Col. - It looks good; thorough and simple enough. One observation if I may; the use of the phrase Coalition Force seems quite Afghan-centric, especially when linked with the examples of ANSF. In this post-Afghan world it may help your survey's acceptability to mirror the Army's latest deployment model of Expeditionary Warfare e.g. non-FOB based operations. If you changed the Coalition Forces to something more generic like 'friendly forces' or perhaps 'allied nations' it might be seized upon as being forward looking and therefore something for the future. Once Army HQ starts looking at the next 'thing' it gathers a momentum all of its own and it makes a lot of difference to hitch your wagon to those particular horses! Having worked at a high level in Army HQ I can vouch that semantics is sadly all-important! It should be the substance that matters and I think your survey asks all the questions to cover all the eventualities if I think back to my time as a Company Commander in Iraq.

Feed back from a Lt. Col. - All very relevant questions that I imagine the majority of those in front line fighting roles have experienced, a couple did seem to be very similar though.

Feed back from Lt. Col.– Great items, concerned a little that you are only collecting form those whom have deployed in the last five years I suggest you extend this to 6 or 7 years.

Feed back from a WO1 - I think the questions are very clear. The wording is fine and neutral therefore not at risk of flashing the lads up with overly complicated terminology.

Feed back from a SSGT– Good stuff, easy to understand and will be easy to report on those who served under you. Most soldiers will have experienced what you have described as long as they aren't a REMF!

Feed back from a CPL– Easy to read and nice to see you using military terms, can't imagine anyone who hasn't experienced them all at some point in their career.

Appendix B

8.2. MR-MO Questionnaire

Performance and Well Being

The questions you will answer next relate to your judgment of the ability of those under your command to maintain a high level of performance even when faced with a potentially challenging situation.

There are 12 questions in total. The individual you report on in this study will not have access to the data you provide about them, nor will your answers be seen by anyone else in the command chain.

For the questions please indicate on the scale 1-7 (1- Never, 7 – Always) how effectively the individual functioned when faced with the described situation before moving on to the next question.

Please take time to consider your response and provide accurate answers.

There are no right or wrong answers; we just want you to provide the most accurate answer you can.

Based on my observations of 'Soldier X' while on an operational deployment, 'Soldier X' is able to maintain a high level of personal performance, even when:

		Key	Never 1	2	Sometimes 3	4	5	Always 6	7	
		Soldier Details (Name & Rank)								
1	**He is suffering from fatigue (e.g., associated with high levels of mental effort).**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**N/A**	
2	It is unclear how and when he will return to a place of safety.	1	2	3	4	5	6	7	N/A	
3	**In a potentially traumatic event.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**N/A**	
4	In the immediate aftermath of a potentially traumatic event.	1	2	3	4	5	6	7	N/A	
5	**He has not had much sleep.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**N/A**	
6	He is under pressure to perform well (e.g., during a hostile contract).	1	2	3	4	5	6	7	N/A	
7	**He is in pain (e.g., associated with high levels of physical effort).**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**N/A**	
8	Fellow team members have been WIA (suffering life changing injuries).	1	2	3	4	5	6	7	N/A	
9	**Required to revisit a location or undertake a task where traumatic events have previously occurred.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**N/A**	
10	The job assigned to him is unpleasant (e.g., handling human remains)	1	2	3	4	5	6	7	N/A	
11	**Elements of the Indigenous Armed Forces have recently attacked British troops.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**N/A**	
12	He has been unable to assist a wounded comrade.	1	2	3	4	5	6	7	N/A	

Appendix C

8.3. Descriptive Statistics Study 3

Measure	Mean (Overall Score)	SD	Mean (Item Response)	SD
MRec	37.5	6.00	5.40	.83
MRp	27.4	3.67	5.55	.76
PCL-M	38.72	10.65	2.25	.62
HADS-Anxiety	13.5	2.87	1.92	.41
HADS-Depression	12.04	2.36	1.72	.33
Reward Sensitivity	27.76	4.97	-	-
Punishment Sensitivity	11.20	8.76	-	-