Loneliness and Hypervigilance to Social Threats in Adults

By

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STUDENT DECLARATION FORM

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Collaboration

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The empirical study described in Chapter 6 was part of a collaborative project with Professors Stephanie and John Cacioppo at the University of Chicago. The candidate was involved in every stage of the project from initial ideas, design, data collection, data analyses, data interpretation and write up of the study.

Signature of Candidate: Nimeal Bayee

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Abstract

A current theoretical model (Cacioppo & Hawkley, 2009) proposes that lonely people are hypervigilant (i.e. on high alert) to social threats in the social environment. This leads to attention, memory, and confirmatory biases, which undermine the opportunity to develop positive social relationships. This thesis outlines a series of six studies that systematically examine the hypervigilance to social threat hypothesis in loneliness using adult samples. The studies described in this thesis make an original contribution to the loneliness literature and uses different experimental paradigms to examine whether lonely adults are hypervigilant to social threats that are visually presented.

Studies 1 and 5 bridge the gap in the current knowledge to examine the visual attention processing of lonely adults to social threat depicted as social rejection stimuli using eye-tracker methodology. Study 2 investigates whether loneliness is associated to eye-gaze and emotion processing utilising a cognitive paradigm. Studies 3 and 4 extend the literature on visual attention processing of lonely adults to investigate the processing of emotional information depicted as facial expressions using eye-tracker methodology. Specifically, study 3 uses a paradigm of four different emotional expressions (i.e. anger, afraid, happy and neutral), and study 4 utilises a face in a crowd paradigm for which different ratios of happy to angry faces were presented. Study 6 extends the work on hypervigilance to social threats depicted as social rejection stimuli to examine how these stimuli are processed by lonely adults in the brain using EEG methodology.

Findings from study 1 and 5 suggest that lonely adults show visual attentional biases to social threat stimuli linked to social rejection. Specifically, study 1 findings indicate that lonely adults show a hypervigilance-avoidance pattern of processing towards social rejection stimuli, whilst study 5 findings indicate that lonely adults show disengagement difficulties when processing social rejection stimuli. Study 2 indicates that loneliness is not associated to eye-gaze and emotion processing. Study 3 and 4 provide support that lonely adults are more attentive to angry facial expressions presented as static images. Findings from study 6 indicate that lonely adults detect and process social threats quickly compared to non-social threats in the brain.

As outlined in Cacioppo and Hawkley's theoretical model, the findings of this thesis support the idea that loneliness is related to initial cognitive processes. Specifically, lonely adults are hypervigilant to social threats depicted as angry facial expressions and social rejection stimuli. Thus, the thesis examines an important process within the model. The findings of the thesis can be used to inform ideas for future academic and intervention work in the loneliness field.

Contents

List of Tables and Figures

Tables

Chapter 4

Figures

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I would like to end with a memory of my college years. My Psychology teacher always used to say to me; “The world is your oyster” – *and she was right…*

Chapter 1: Introduction to Loneliness Research

Definition

Loneliness is an aversive state caused by a perceived discrepancy between the social relationships an individual currently has and those he/she wishes to have (Peplau & Perlman, 1982). This definition embodies the three main elements that are commonly used by theorists to describe loneliness: (1) it is a subjective experience, (2) it is an unpleasant/distressing feeling, and (3) it results from a deficiency in social relationships. Also, the above definition emphasises the cognitive aspect of loneliness, such that it is related to the perceptual and subjective appraisals of individuals' expectations that social relationships are not being met adequately (Heinrich & Gullone, 2006).

Feeling lonely is a part of everyday life and people are likely to experience loneliness at various points of their lives during childhood, adulthood and older age (Heinrich & Gullone, 2006). Research shows that feeling lonely leads to a number of mental and physical health issues (Heinrich & Gullone, 2006); loneliness has comparable effects to smoking and has greater effects than obesity on early mortality (Holt-Lunstad, Smith & Layton, 2010). In addition, statistics show that the general public believe more and more people are feeling lonely (Griffin, 2010). Thus, there has been an increased need to understand what mechanisms are involved in the maintenance of loneliness and what processes are involved in keeping those feelings of loneliness intact. Specifically, this thesis aims to increase research in that area by focussing on understanding the cognitive aspects (e.g. processes and biases) of loneliness and how these cognitions are involved in maintaining the feelings of loneliness. The research findings of this thesis are likely to offer ideas for interventions based on targeting the maladaptive cognitions a lonely person has. This is likely to benefit those people with chronic loneliness and the mental health professions who support them.

The term loneliness has been interchangeably used in the literature with related constructs such as social isolation and being alone. However, empirical evidence suggests that these are distinguishable from loneliness. For example, lonely people compared to non-lonely do not differ in the amount of time they spend alone (Hawkley, Burleson, Berntson & Cacioppo, 2003), nor do they report having fewer close friendships (Russell, Cutrona, McRae & Gomez, 2012). When asked about perceptions of loneliness, adolescents describe loneliness negatively and relate it to negative emotions such as sadness, while aloneness is perceived as more of a neutral state (Buchholz & Catton, 1999). This suggests that loneliness is not synonymous with being alone and, in fact, aloneness may be a positive or desirable state, which promotes concentration, creativity and thinking (Larson, 1999). Similarly, social isolation is an objective measure that is quantifiable with one's social network and the need for social contact, whereas loneliness is to do with the quality of these desired social relationships. In support of this, Coyle and Dugan (2012) found that the two constructs were not highly correlated.

Loneliness is also reported in childhood. Children as young as five years of age report loneliness (Cassidy & Asher, 1992; Coplan, Closson & Arbeau, 2007) and very much define it in regards to theory, such that loneliness is a sad feeling and involves having no one to play with. But at this stage, their understanding that loneliness can also be experienced in the presence of other people is limited (Asher & Paquette, 2003) and this notion is only developed from the age of 8 years and above (Galanaki, 2004). Children conceptualise loneliness in ways that are similar to that reported in the adult literature. For instance, they talk about loneliness in terms of the emotional domain (i.e. feeling sad), cognitive domain (i.e. a relationship disparity), and the context domain (i.e. physical and psychological contexts) that forms the basic understanding of the concept of loneliness in both children and adults. Furthermore, school-aged children are able to understand the difference between loneliness and aloneness (Galanaki, 2004; Liepins & Cline, 2011), such that being alone does not necessarily mean one is lonely and feeling lonely does not mean being alone. The theoretical and empirical research suggests that children show a uniform understanding of loneliness.

However, from childhood to adolescence the level of contact and relationships' an individual desires and values varies, suggesting a different experience of loneliness feelings with increasing age. Parkhurst and Hopmeyer (1999) propose a model that includes both the cognitive and developmental bases in explaining the causes of loneliness. They argue that in early to late childhood, the feelings of loneliness are driven by a lack of physical contact and proximity with peers. Cognitions involved at this stage are associated with the child feeling as though they have no one to play with, having no friends, and feelings of rejection by peers. Loneliness in childhood is primarily influenced by peer acceptance and friendships are formed based on the need of companionship and undertaking shared activities. During early to late adolescence, a shift occurs with the quality of friendships and romantic relationships become important in providing a sense of belonging, identity, self-value and intimacy (Collins, Welsh & Furman, 2009; Steinberg & Morris, 2001). In adolescence, feelings of loneliness are experienced psychologically such that adolescents feel as though they have no one to confide in and talk to, no sense of belonging or understanding, and can feel a lack of intimate relationships.

As well as a change in the desired social relationships from childhood to adolescence, the value of social relationships also differs throughout adulthood. Great emphasis is placed on the quality of friendships and the need for committed and steady romantic relationships for adults; the lack of these intimate social relationships is highly related to the feeling of loneliness (Diener, Gohm, Suh & Oishi, 2000; Flora & Segrin, 2000; Givertz, Woszidlo, Segrin & Knutson, 2013). Dykstra, Van Tilburg and de Jong-Gierveld (2005) suggest that for adults aged 65 and over, feelings of loneliness may increase due the loss of existing social ties. For instance, the loss of partners, loss of peers, increased dependency, and reduction in social activities gives rise to loneliness. Therefore, loneliness for older adults may reflect more of a change in existing relationships than to a change in desired relationships as seen for children, adolescents and adults. The literature suggests that changes in the sources of loneliness differ across development and that there is a steady change from simply wanting someone to play with to a focus on intimacy and life-partnership. (See Qualter et al, 2015 for a review of loneliness across the life-span).

Assessment of loneliness in children, adolescents and adults

Loneliness is a subjective experience and is not homologous to objective/quantifiable features, so it is assessed using self-report measures in children, adolescents and adults. Assessment of loneliness can vary from using a single question item to multiple questionnaire items. In adults, the most common loneliness self-report measure used by researchers is the University of California Los Angeles (UCLA) Loneliness scale (Russell, 1996). The UCLA comprises twenty questions: 11 negatively worded (i.e. How often do you feel left out?) and 9 positively worded (i.e. How often do you feel there are people you can turn to?); with respondents scoring on a 4-point scale (1 = never; 2 = rarely, 3 = sometimes; 4 = often). The scale does not include the word “lonely” in any of the questions in order to avoid the social stigma associated with loneliness (de Jong Gierveld, Van Tilburg, & Dykstra, 2006), but measures the deficiency caused by different social relationships. The UCLA scale takes a global/unidimensional approach and assumes that feelings of loneliness are the same across all deficiencies caused within social relationships. For school-aged children and adolescents, the Loneliness and Social Dissatisfaction Measure (Asher & Wheeler, 1985) is a commonly used measure and this takes a unidimensional approach. This measure includes 16 items for loneliness with some questions directly addressing loneliness (e.g. “I am lonely”), and others addressing the appraisals of current peer relationships (e.g. “I don’t have any friends”), appraisals of whether social needs are met and appraisals of one’s social self. The above measure is a modified version to the original and specifically looks at loneliness and social dissatisfaction in the school context rather than looking at it in everyday life.

However, many theorists suggest that loneliness is a multidimensional construct with deficits in different social relationships relating to different forms of loneliness. For example, Weiss (1973) makes the distinction that there are different types of loneliness; social and emotional loneliness. Social loneliness is described as an absence of relationships (i.e. friends) in one’s social network, whilst emotional loneliness arises due to the absence of an intimate attachment (partner or close friend). In accordance with the above distinction, assessment measures have been developed that differentiate between emotional and social loneliness. For instance in adults, the de Jong-Gierveld scale (1987) includes 6 items measuring emotional loneliness and 5 items measuring social loneliness. For children and adolescents, the Peer Network and Dyadic Loneliness Scale (PNDLS; Hoza, Bukowski & Beery, 2000) includes 8 measures assessing peer network loneliness (i.e. social loneliness) and 8 items assessing peer dyadic loneliness (i.e. emotional loneliness).

Certain scales also assess the specific type of social relationships that may be deficient in a lonely person’s life. For example the Social and Emotional Loneliness Scale for Adults (DiTommaso & Spinner, 1993; 1997) identifies satisfaction with romantic, family and social relationships, and the Differential Loneliness scale (Schmidt & Sermat, 1983) assesses satisfaction with friendship, family, romantic and group level relationships. Likewise, multidimensional measures have been developed to use for children and adolescents. The Louvain Loneliness Scale for Children and Adolescents (LLCA; Macroen, Goossens & Caes, 1987, renamed the Loneliness and Aloneness Scale for Children and Adolescents) assesses loneliness in four different social relationships classed as peer loneliness, parent loneliness, aversion to aloneness and affinity to aloneness. The 48-item scale contains 12 measures for each subscale.

Different measures for assessing loneliness have been developed based on the assumption of whether it is construed as a unidimensional or multidimensional construct. This thesis conceptualises loneliness as a unitary phenomenon and takes the view that the emotional feelings of loneliness are the same for all individuals who feel lonely and only differ in intensity. The aim of this thesis was not to examine the deficits of different social relationships (i.e. caused by a lack of friends or family), but was rather to assess the level of loneliness within the study samples focussing on the emotional feelings of loneliness. Taking this into account, all the studies described in the thesis have assessed loneliness using the frequently used UCLA loneliness scale in adult samples, with high internal consistency being reported for the scale ($\alpha = 0.89 – 0.94$). In addition, the UCLA loneliness scale was chosen for the studies in this thesis because (1) the scale does not refer to the words ‘lonely’ or ‘loneliness’ in any of the questions, which may generate more accurate answers by avoiding the social stigma associated with loneliness, (2) the UCLA scale provides a ‘pure’ loneliness score that taps into the emotional feelings of loneliness, which this thesis explores.

Perspectives on loneliness

Theorists have put forward different perspectives on the causes and maintenance of loneliness. There are four main perspectives on loneliness: psychodynamic approach, social needs approach, cognitive discrepancy approach, and evolutionary approach. These are discussed below (see Heinrich & Gullone, 2006; Peplau & Perlman, 1982; Weeks & Asher, 2012 for detailed reviews). Currently, most loneliness researchers examine the concept of loneliness in relation to the evolutionary perspective.

Psychodynamic perspective

The psychodynamic approach assumes that loneliness stems from early experiences and is associated with individual factors such as personality traits. Specifically, an early theorist Zilboorg (1938 cited in Peplau and Perlman, 1982) argued that (unhealthy) narcissism developed in the mother-child relationship leads to very high expectations of interpersonal relationships that cannot be fulfilled, leading to chronic disappointment in current and future relationships, which cause loneliness. Similarly, Fromm-Reichmann (1959) suggests that the negative consequences of “premature weaning from mothering tenderness” results in loneliness and causes people to remain disconnected from others. This approach has received little empirical examination by researchers in comparison to the other perspectives described below and in a recent review Weeks and Asher (2012) suggest that ideas about the role of relationship expectations in the development of loneliness over time should be further investigated.

Social needs perspective

The social needs approach (Sullivan, 1953; Weiss, 1973) suggests that loneliness is caused by a deficiency in relationships that is important to one’s inherent social needs identified as six provisions (i.e. attachment, social integration, reliance alliance, guidance, nurturance, reassurance of worth). According to this approach, a person experiences loneliness if their social relationships do not satisfy an inherent set of provisions. Weiss (1973) further argued that specific types of relationship deficits give rise to different forms of loneliness (i.e. emotional and social loneliness). Emotional loneliness arises due to the lack of an intimate attachment figure (i.e. close friend or partner), while social loneliness arises from the absence of relationships (i.e. friends) from one’s social network. Hence the two provisions of attachment and social integration directly map onto the different forms of loneliness.

The social needs approach is highly influenced by Bowlby’s attachment theory (Bowlby, 1969), which indicates that intimate attachment bonds between children and parents/primary caregivers in early life are important precursors for developing close social relationships with others in later life. Studies have shown that high loneliness levels in adults are associated with insecure attachment styles, and low loneliness levels are associated with secure attachment styles in early life (DiTommaso, Brannen-McNulty, Ross & Burgess, 2003; Hecht & Baum, 1984; Wiseman, Maysless & Sharabany, 2006). Likewise, childhood loneliness is consistent with an insecure-ambivalent attachment in infancy (Berlin, Cassidy & Belsky, 1995). This approach highlights the role of early life factors in the cause of loneliness identified as inherent social needs.

Cognitive discrepancy perspective

In contrast to the social needs approach, the cognitive discrepancy approach accentuate the primary cause of loneliness to the role of an individual's cognitions that are involved in the perception and evaluation of their social relationships. Specifically, Peplau & Perlman (1982) propose that loneliness occurs when an individual perceives a discrepancy between the desired and actual levels of social relationships. This discrepancy can either be observed at a quantitative or qualitative level, but both require the subjective appraisal of dissatisfaction with relationships in some way. This approach is influenced by attribution theory and implies that a person's negative thoughts and behaviours about themselves and others are associated with loneliness. For instance, research indicates that lonely people across development blame themselves (i.e. internal attributions) when explaining the causes of their social exclusions (Qualter & Munn, 2002; Solano, 1987) and social difficulties (Crick & Ladd, 1993).

Evolutionary perspective

The evolutionary approach to loneliness is grounded in the notion that humans, by nature, are a social species with an innate need to belong and with a "desire to form and maintain at least a minimum quantity of lasting, positive and significant interpersonal relationships" with others (Baumeister & Leary, 1995 p. 497). Evolutionary psychologists argue that the need to belong appears to be an evolutionary advantage for survival from prehistoric times. This was because those who were able to form and maintain positive relationships in social groups were more likely to survive: members shared necessities (i.e. food and shelter), formed hunting groups, offered protection and the chance to reproduce to ensure the survival of their genes. Therefore, loneliness is thought to have had a functional purpose (Cacioppo & Patrick, 2008) for our ancestors and has evolved from this in modern society.

Recently, theorists (e.g. Cacioppo, Cacioppo & Boomsma, 2014) suggested that feelings of loneliness evolved in a similar manner to hunger, thirst or pain signals, which motivate individuals to change their behaviour and take action to reduce damage to one's physical health and well-being. For example, feeling hungry motivates the individual to search for food; likewise, feeling lonely motivates an individual to search for social connections. Thereby, loneliness is an aversive signal that highlights to individuals that social connections with others are at risk, and motivates them to re-connect with others by putting the brain on high alert (hypervigilance) for social threat in an attempt to reduce social pain (Cacioppo et al, 2006; Cacioppo et al, 2014). In such a way, loneliness is thought to be an adaptive response because it signals to an individual to seek out friends or make new social connections to alleviate this social pain. However, loneliness is a cause of major concern for mental and physical health. Loneliness has those negative implications if an individual responds to the loneliness signal in a maladaptive way by showing behavioural changes (e.g. social withdrawal) or due to individual differences (e.g. genetics) that prevents them from connecting with others in the social environment (Cacioppo et al, 2014). Much of the research has been focussed on the maladaptive consequences of the loneliness signal as this is related to the chronicity and severity of the condition, while little research has examined the adaptive response and the ability to overcome loneliness in everyday life by making social connections. Additionally, it has been suggested that the risk to one's social connections (i.e. social pain system) and physical pain system have developed hand in hand to promote survival, with neural pathways of both social and physical pain sharing the same pain matrix, and demonstrating activation in similar regions of the brain (Eisenberger, Lieberman & Williams, 2003; MacDonald & Leary, 2005).

Genetic component of loneliness

In line with the evolutionary origins of the loneliness perspective, researchers have investigated whether loneliness is in part influenced by genetic contributions. Studies indicate that loneliness in linked to heritability among twins with estimates of 55% for children (McGuire & Clifford, 2000) and 48% for adults (Boomsma, Willlemsen, Dolan, Hawkley & Cacioppo, 2005). Specific genes have also been implicated in the development of loneliness

(Lucht et al, 2009; Van Roekel, Scholte, Verhagen, Goossens & Engels, 2010). Further research should focus on the specific genetic profiles of lonely people and research the mechanisms involved in the development of loneliness across the lifespan.

Prevalence of loneliness

Loneliness is a universal experience and felt by people of different ages, gender, marital status, and socioeconomic status (Heinrich & Gullone, 2006). Feeling lonely is prevalent amongst children, adults and older adults. A report suggests a rise in childhood loneliness in 2008-2009 with prevalence rates tripling in the past five years (National Society for the Prevention of Cruelty in Children; NSPCC; Hutchinson & Woods, 2010). In adulthood, prevalence statistics show that 1 in 20 adults feel completely lonely (Office of National Statistics survey 2011; Randall, 2012). Furthermore, the Mental Health Foundation survey in the UK reports that out of a sample of 2,256 people, one in ten (11%) felt lonely often and 22% of people never felt lonely; 48% believed people are getting lonelier in general (Griffin, 2010). Also, the prevalence of severe loneliness in older adults aged over 65 years is estimated at 7% in the UK (Victor, Scambler, Bowling & Bond, 2005). Loneliness is not only common across the life-span, it is also a global phenomenon reported all across the world. Recently, Yang and Victor (2011) showed loneliness to be prevalent in twenty-five European countries, with Russia and eastern European countries having the highest rate of frequently lonely responders (10 to 34%), while countries in northern Europe have the lowest rate (6%). Also, 35% of older adults in the United States are characterised as being lonely in a recent survey (Wilson & Moulton, 2010). These statistics suggest that loneliness is common across different age groups and different countries in contemporary society.

It is important to examine the course of loneliness from childhood to adulthood because feelings of loneliness are reported across the lifespan. Loneliness appears to follow the pattern of peaking in early adolescence, dropping in early and middle adulthood, and increasing slightly in older adulthood (Heinrich & Gullone, 2006). However, analyses that examine the growth of loneliness at an individual level over time have identified distinct groups of lonely people who follow different trajectories of loneliness. Recently, using longitudinal designs, different developmental trajectories of loneliness have been reported. In childhood (9 to 11 years of age), Jobe-Shields, Cohen and Parra (2011) reported a large proportion of low and stable lonely group, increasing lonely group, and a small proportion of elevated and decreasing lonely group. Similarly, Qualter et al., (2013a) examined loneliness trajectories from childhood to adolescence (age 7 to 17 years) and found four distinctive groups: (1) low and stable, (2) moderate increasers, (3) moderate decliners, and (4) high stable loneliness. In addition, similar trajectory groups were reported for two samples in the United States (Ladd & Ettekal, 2013; Schinka, Van Dulmen, Mata, Bossarte & Swahn, 2013) and from data collected in the Netherlands (Vanhalst, Goossens, Luyckx, Scholte & Engels, 2013). All of these studies suggest that distinct lonely groups are apparent from childhood to early adulthood (ages 7 to 20 years).

Interestingly, distinct groups of lonely older adults follow the same pattern. Over a seven year period, Dykstra, Van Tilburg and de Jong-Gierveld (2005) reported that in their sample, 70% of loneliness responders remained the same on loneliness levels, 10 to 13% decreased for loneliness responding and 11 to 18% increased for loneliness responding. Most recently, in a survey over a 10 year period, two-thirds of the participants were classed as stable lonely, 25% decreased in loneliness, 15% increased in loneliness, and 20 to 25% had a persistent level of loneliness (Victor, 2013). Longitudinal data from different age groups (children to early adulthood and older adults) suggest that loneliness for some people is a transient experience, whilst for others it is a chronic and persistent experience.

Transient versus chronic loneliness

Loneliness can either be felt for shorter periods of time (transient) that can be influenced by changes in circumstances (i.e. moving away from home), or felt for longer periods of time (chronic) making it a more severe state (Young, 1982). People can either feel lonely for a short duration or long duration, but transient loneliness can be just as intense and severe as chronic loneliness. Early theorists also propose that transient and chronic loneliness map onto state and trait loneliness respectively (Jones, Rose & Russell, 1990). Transient loneliness is likely to be felt by people at some point in their lifetime and can be adaptive, but when this becomes chronic (maladaptive) it is a cause for concern due to the effects on health (Cacioppo et al, 2002b). Recent research has only just begun to examine the individual effects of transient/situational and chronic loneliness on mortality; both types were found to contribute to early mortality risks, with chronically lonely individuals having a slightly higher risk (Shiovitz-Ezra & Ayalon, 2010). Therefore both transient and chronic loneliness is thought to lead to adverse health outcomes.

Loneliness and Health

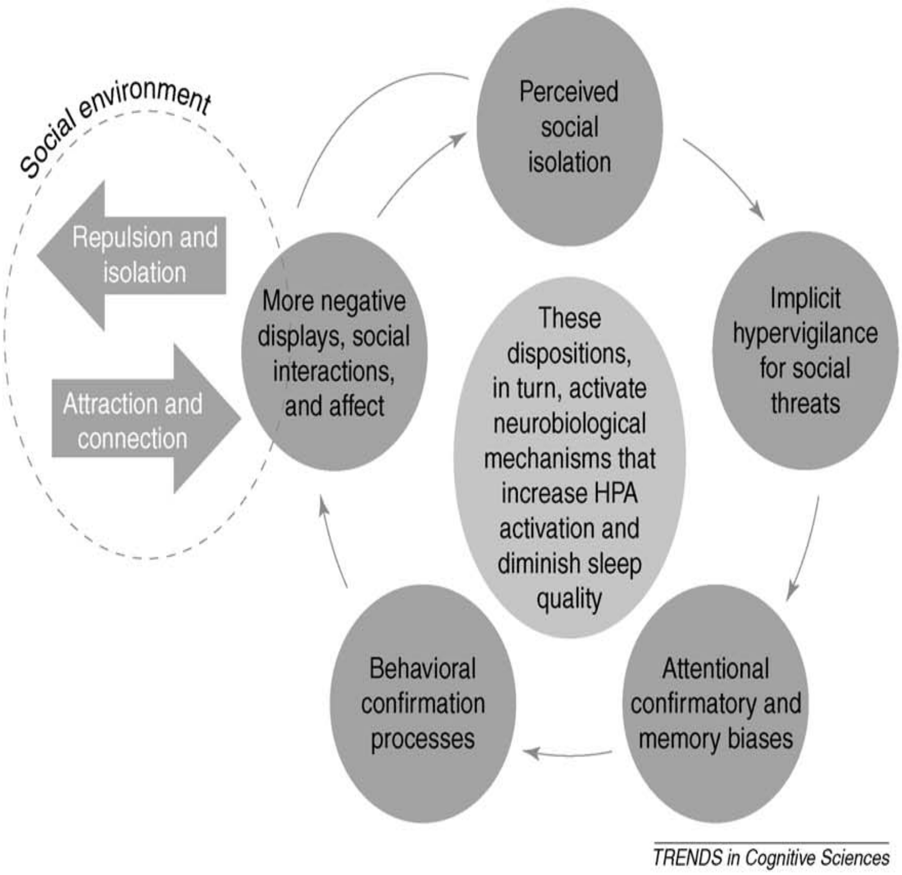
The qualities of individuals' social relationships are thought to play a central and beneficial role in mental and physical health. Holt-Lunstad, Smith and Layton (2010) meta-analysis highlighted that individuals with poor or insufficient social relationships have an increased risk of early mortality than those with stronger social relationships. The findings also indicate that the effect of social relationships on mortality were far greater than the effect of reduced physical activity or obesity, and showed comparable effects to alcohol consumption and smoking on death, suggesting the central importance of social relationships to humans. Similarly, Baumeister and Leary (1995) suggest that when belonging needs are not fulfilled, an individual experiences mental and physical consequences. In addition, trajectory studies (e.g. Qualter et al, 2013a) show that loneliness is a normative experience, but for some lonely people it is a prolonged experience associated with poor health outcomes. These studies suggest that loneliness (i.e. perceived social isolation) can have detrimental effects on mental and physical health and a theoretical model suggests the complex factors that link loneliness to poor health outcomes.

The loneliness model

Based on the evolutionary perspective of loneliness, Cacioppo and Hawkley (2009) propose a theoretical model of how loneliness is associated with poor health. Within this model, the authors suggest that lonely individuals are hypervigilant to social threats in the environment, which causes attention, memory, and confirmatory biases. Thereby, lonely people remember more negative social events, attend to negative social information, see the world as more threatening, and hold more negative social expectations than non-lonely people. These biases cause the lonely person to behave in a certain way, which elicits behaviours from others that support the lonely person's viewpoint; in effect, lonely people actively distance themselves from those people who they need to fulfil their social needs. These biases are thought to (1) undermine the opportunity to form and maintain positive social relationships resulting in more feelings of loneliness and being stuck in a self-reinforcing loop where they feel low self-worth, anxiety, stress and hostility, and (2) activate neurobiological mechanisms that increase the functioning of the hypothalamus-pituitary-adrenal (HPA) axis and diminish sleep quality. Chronic activation of threat surveillances contributes to an increase cognitive load, diminish executive functioning, dysregulate brain and physiological systems, and adversely affect health (see Figure 1.1).

Cacioppo and Hawkley's (2009) loneliness model is currently the only theory that proposes how perceived social isolation (i.e. loneliness) leads to poor health by indicating a number of interacting factors in this complex relationship. This model is heavily influenced by the evolutionary perspective of loneliness that suggests loneliness is an evolutionary signal that promotes individuals to repair and strengthen social relationships that contribute to better health and well-being, and survival of one's genes (Cacioppo et al, 2014). In their model, Cacioppo and Hawkley (2009) imply that people become chronically lonely when they are stuck in the self-regulatory loop which is caused by maladaptive cognitions. Whilst at some point in the model, transiently lonely people are able to leave the self-regulatory loop by making social connections and thus avoid the health consequences of prolonged loneliness. The model was initially developed to find a link between loneliness and poor health, but a number of cognitive processes are involved in that relationship which have received little systematic examination. The main focus of the current thesis and the subsequent empirical chapters are examining these cognitive processes (i.e. implicit hypervigilance to social threats) within Cacioppo and Hawkley's model.

Figure 1.1: The effects of loneliness on human cognition and associations to poor health (Cacioppo & Hawkley, 2009)



Evidence linking loneliness to poor physical health

In the literature, there is a large amount of research investigating the link between loneliness and poor physical health. Cacioppo and Hawkley's (2009) loneliness model suggests that prolonged feelings of loneliness are associated with poor health outcomes by chronic activation of neurobiological mechanisms that increase the functioning of the hypothalamus-pituitary-adrenal (HPA) axis and physiological (I.e. cardiovascular) systems leading to a greater risk of early mortality and morbidity for lonely individuals. Even though the main focus of this thesis is on the initial cognitive processes in this model, the empirical evidence supporting the health aspects are discussed below, so the evidence supporting that aspect of the model is provided.

Prolonged HPA activation

Cacioppo and Hawkley (2009) argue that loneliness is associated with poor health by chronic activation of the HPA axis caused by a heightened alertness for social threats. Based on this assumption lonely people are likely to have increased cortisol levels, which is the main parameter in the HPA response measurable in saliva and urine samples. In naturalistic settings, it was found that lonely psychiatric inpatients secreted more urinary cortisol then non-lonely psychiatric inpatients (Kiecolt-Glaser, Garner, Speicher, Penn, Holliday & Glaser, 1984a; Kiecolt-Glaser et al, 1984b). In healthy populations, lonely adolescents and adults were found to show an increase in salivary cortisol levels at awakening, known as the cortisol awakening response, compared to non-lonely individuals (Doane & Adam, 2010; Steptoe, Owen, Kunz-Ebrecht & Brydon, 2004). Similarly, Cacioppo et al., (2000) reported increased mean cortisol levels in daily life for lonely adults. Previous days feelings of loneliness were related to an increased cortisol awakening response the following day for lonely older adults (Adams, Hawkley, Kudielka & Cacioppo, 2006). However, inconsistent findings have been reported for HPA activation in response to laboratory tasks and real life social challenges. Steptoe et al, (2004) failed to find any differences in cortisol levels between lonely and non-lonely adults after they had performed two mental stress tasks. Also, lonely adults did not differ in cortisol levels to social challenges (i.e. meeting strangers for the first time and giving a speech to peers: Harris, 2014). To date, this area is under researched and future studies are needed to examine the HPA activation in response to social threats as proposed in Cacioppo and Hawkley's (2009) model.

Prolonged physiological activation

The functioning of the cardiovascular system has been implicated in the link between loneliness and poor health. Lonely adults differ from non-lonely adults in heart rate reactivity in response to acute psychological stressors (i.e. mental arithmetic and public speaking) (Cacioppo et al, 2000). Studies also report that loneliness is related to higher diastolic blood pressure during a mental stress task in women (Steptoe et al, 2004), and differential blood pressure reactivity to the Trier Social Stress Test that includes public speaking and mental arithmetic tasks (Nausheen, Gidron, Gregg, Tissarchondou & Peveler, 2007; Ong, Rothstein & Uchino, 2012). However, findings from cardiovascular measures are less consistent in the loneliness literature with some studies reporting no association between the two factors because high variability across individuals exists overall (Kamarck & Lovallo, 2003).

Repair and restorative mechanisms

Loneliness has also been shown to affect physiological processes that maintain, recover, and repair the body. One of these restorative processes is sleep. In healthy populations sleep deprivation is associated with poor cognitive processes (Lim & Dinges, 2008) and greater risk of cardiovascular disease (Mullington, Haack, Toth, Serrador, & Meier-Ewert, 2009). Lonely adults were not found to differ in the amount of time spent in bed, but they spent less time sleeping and had more micro-awakenings compared to non-lonely adults, when sleep was recorded objectively (Cacioppo et al, 2002a). However, in a diary study, lonely adults self-reported more sleepiness, fatigue and lower energy levels (i.e. greater daytime dysfunctions) compared to their non-lonely counterparts, which was irrespective of sleep duration (Hawkley, Preacher & Cacioppo, 2010). Mahon (1994) found that lonely adolescents reported greater disturbances in sleep, but no differences were reported in the amount of sleep as a function of loneliness. In addition, lonely children reported greater sleep disturbances than non-lonely children (Harris, Qualter & Robinson, 2013). Together these studies suggest that the quality of sleep may be a factor in linking loneliness to poor health.

Poor immune functioning is another factor implicated in loneliness. For instance, lonely medical students and lonely psychiatric inpatients had reduced natural killer cells activity involved in anti-viral and anti-tumour responses compared to their non-lonely counterparts in some studies (Kiecolt-Glaser et al, 1984a, 1984b). Those who were lonely compared to non-lonely had lower antibody response to the influenza vaccination (Pressman et al, 2005), suggesting that the normal antibody response is deregulated in lonely people. Further, diminished inflammatory processes are associated with loneliness. Lonely adults were observed to overexpress pro-inflammatory genes and underexpress anti-inflammatory genes in comparison to non-lonely adults (Cole et al, 2007). Specifically, lonely adults had higher levels of the pro-inflammatory cytokine interleukin-6 to acute stress (Hackett, Hamer, Endrighi, Brydon & Steptoe, 2012; Jaremka et al, 2013). All these studies suggest that immune dysregulation including impaired inflammatory processes is a potential pathway linking loneliness to poor health outcomes.

Health behaviours

However, loneliness may affect health in an indirect manner by lonely people undertaking more behaviours that are a risk to their health and/or avoid behaviours that are beneficial to health. Inconsistent findings have been reported using surveys. One survey indicates that lonely young adults do not differ on health behaviours such as tobacco and caffeine consumption, body mass index, or on weekly exercise sessions than the non-lonely (Cacioppo et al, 2002b). In fact, lonely young adults reported consuming slightly less alcohol than their counterparts (Cacioppo et al, 2000). Similar findings were found in a sample of older lonely adults with no differences reported for the frequency of health behaviours (Cacioppo et al, 2002b). However, another survey suggests that lonely adults are more likely to be smokers, more likely to be obese, and have a higher body mass index score (Lauder, Mummery, Jones, & Caperchione, 2006). More recently, loneliness was linked to an increased risk of smoking in a nationally representative sample of adults and late adolescents (DeWall & Pond Jr, 2011). These authors argue that lonely people are more likely to be smokers in an attempt to gain social acceptance by others and satisfy their belonging needs. This was supported by their finding that loneliness had a stronger impact on smoking behaviour in those areas where smoking was more socially accepted. All these studies have relied on retrospective self-reports; those are biased and rely on participants' memory. More reliable measures such as experience sampling studies known as beeper studies failed to find an association between loneliness and these health behaviours (Hawkley et al, 2003). The inconsistencies in the findings suggest that health behaviours play only a small part in linking loneliness to poor health and it is likely that frequencies of health behaviours cannot sufficiently explain poor health.

However, Hawkley, Thisted and Cacioppo (2009) and Newall, Chipperfield, Bailis and Stewart (2013) indicate physical activity as a specific risk behavior: lonely older adults were found to engage in less physical activity over time. In line with the above findings, lonely older adults (Shankar, McMunn, Banks & Steptoe, 2011) and lonely adolescents were also found to be less physically active, but this finding was not replicated for lonely children (Page &

Tucker, 1994). Physical activity is thought to be beneficial to one's cognition, mental and physical health (Penedo & Dahn, 2005; Sofi et al, 2011). The ability to self-regulate health and emotions may be diminished in lonely people (Hawkley et al, 2009), which could explain how certain health behaviours relate to poor health.

Loneliness and mental health

Loneliness has negative implications for cognition, emotion, behaviour, and overall physical health, but it has also been shown to affect mental health and intensify mental disorders. Psychosocial difficulties such as shyness, neuroticism, social withdrawal and self-esteem, and mental health difficulties such as suicidal thoughts, anxiety and depression are all known and studied correlates of loneliness (Heinrich & Gullone, 2006).

Much research on loneliness and mental health has focused on depression as a health outcome. In adults, longitudinal studies indicate that feelings of loneliness predict increases in depressive symptoms (Cacioppo, Hughes, Waites, Hawkley & Thisted, 2006; Cacioppo, Hawkley & Thisted, 2010; Vanhalst, Luyckx, Teppers & Goossens, 2012). Similarly, longitudinal studies show that loneliness predicts increase in depression symptoms for children and adolescents who feel lonely during this period (Ladd & Ettekal, 2013; Qualter et al, 2010; Qualter et al, 2013a; Schinka et al, 2013).

Summary: loneliness and health

Evidence from empirical studies supports the notion that loneliness adversely affects health (physical and mental). However, it is also important to examine the cognitive processes involved in the relationship between loneliness and poor health, as these are given such a prominent place in the model proposed by Cacioppo and Hawkley (2009). The following section discusses the cognitive biases associated with loneliness as part of Cacioppo and Hawley's model (refer to Figure 1.1).

Loneliness and Cognition

Cacioppo and Hawkley's (2009) model hypothesises that feeling lonely causes a heightened vigilance (hypervigilance) to social threats. Lonely people are more likely to attend to and remember negative social information, hold more negative social expectations, and perceive the social world as more threatening. These biases cause some lonely people to behave in a certain way, which elicits behaviours from others that support the lonely person's viewpoint. This undermines the opportunity to form and maintain positive social relationships resulting in more feelings of loneliness. Therefore, some lonely people are stuck in a self-reinforcing loop of negativity, whilst some lonely people are able to use the feelings of loneliness in an adaptive manner (i.e. reconnection with others) and leave the loop.

Evidence linking loneliness and cognition

Many studies have reported an association between loneliness and cognition with some evidence supporting the theory put forward by Cacioppo and Hawkley (2009). In accordance with the model, supporting evidence can be found for (a) attentional/memory biases, (b) perceptual biases, (c) behavioural biases and (d) differences in brain functioning and brain structure. These studies have utilised different methodologies to assess cognitive deficits associated with loneliness, for instance; self-ratings, cognitive paradigms, eye-tracker technology, observational methodology and neuroimaging techniques. Evidence for cognitive biases in loneliness is discussed below.

Overall cognitive decline in loneliness

Longitudinal studies suggest that loneliness is a risk factor for cognitive decline in older adults (Shankar, Hamer, McMunn & Steptoe, 2013). A study by Tilvis et al., (2004) found that loneliness was independently related to cognitive decline in a prospect study measuring cognition at baseline, 1-year, 5-year and 10-year follow-ups. Similarly, lonely people had poorer cognitive abilities (i.e. working memory, episodic memory, sematic memory, perceptual speed and visual-spatial ability) at baseline and had more rapid cognitive decline on most of these domains during the four-year follow up (Wilson et al, 2007). The above study also found an association between loneliness and the development of Alzheimer's disease, with lonely people more likely to be at risk of developing Alzheimer like symptoms compared to non-lonely people. Longitudinal studies examining cognitive decline in lonely children, adolescents and adults have not been conducted to date.

(a) Evidence for attentional/memory biases

Consistent evidence shows that loneliness increases attention to negative *social* information. An fMRI study found that lonely adults have greater neural responses to negative social pictures and reduced neural responses to positive social pictures (Cacioppo, Norris, Decety, Monteleone, & Nusbaum, 2009). One study utilising a cognitive paradigm (modified version of the emotional stroop task) also supports this notion. During emotional stroop tasks, participants are asked to name the colour of words (i.e. threat and neutral/positive) written in different inks colours and longer reaction times or greater stroop interference in naming the colour of threat words relative to neutral/positive words indicate an attentional bias to threat stimuli. Egidi, Shintel, Cacioppo & Nusbaum (2008) found that lonely adults showed a greater interference for negative social words (e.g. disliked, alone, rejected) compared to non-lonely adults. No differences in processing of positive social words were reported in the study. These studies suggest that loneliness primes people to look for negativity in the social world.

However, the use of an emotional stroop task as a measure of selective attention has been criticized. For instance, longer reaction times in this task could mean that the participants failed to make a reaction because of the emotional content. The stroop task also fails to detangle whether the threatening information initially draws attention or holds attention in later processing of stimuli (Bogels & Mansell, 2004; Fox, Russo, Bowles & Dutton 2001). Therefore, findings from Egidi et al's (2008) study do not necessarily support the idea that lonely adults are hypervigilance to socially threatening words because the cognitive paradigm used is not a reliable measure of this. Further, cognitive studies need to directly examine whether lonely people are in fact hypervigilant to social threats that is thought to lead to attention biases in loneliness.

Most recently, one study has directly assessed the hypervigilance to social threat hypothesis within Cacioppo and Hawkley's model using eye-tracker methodology. Lonely children (aged 8 -12 years) showed visual attentional biases to real-life video footage of socially threatening stimuli, depicting scenes of social rejection or social exclusion (Qualter et al, 2013b: study 3). Lonely children did not differ on their first fixation, but lonely children were unable to relocate attention from the social threat stimuli in the initial four seconds of viewing time, in comparison to non-lonely children. This study is a direct assessment of the hypervigilance to social threat stimuli in children. However, one should not assume that same visual attentional processing styles also occurs for a lonely adults sample because cognitive ability and skill is known to differ during childhood to adulthood (Anderson, 2002). Specifically, developmental changes in cognitive processing such as attention relocation (Casey, Galvan & Hare, 2005) and changes in strategies for thinking about the intentions of others (Blakemore, den Ouden, Choudhurry & Firth, 2007) have been found. Therefore, visual attentional biases of lonely adults may be different to those of lonely children and this needs to be examined in the literature.

Loneliness has also been associated with memory biases. A study conducted by Gardner, Jefferies, Pickett and Knowles (2005) showed that lonely adults recalled more social events (both positive and negative) when asked to read diary extracts of others compared to non-lonely adults, implying that enhanced social monitoring may be associated with loneliness. However, children scoring high on loneliness did not recall more social events than non-lonely children (Harris, 2014). Furthermore, adults reporting fewer close friends were more accurate at identifying emotions from faces and showed greater attention to emotional vocal tones (Gardner et al, 2005).

In addition, lonely adults also show a general difficulty in attentional control. During a dichotic listening task, participants were asked to identify consonant-vowel pairs in their right or left ear (Cacioppo et al., 2000). Lonely young adults showed poorer attentional regulation when asked to focus on the left ear over a typical right-ear advantage compared with non-lonely adults. This suggests that loneliness may relate to an inability to shift attention and/or poor self-regulation. Similarly, lonely children showed difficulties in attentional control compared to non-lonely children during a dichotic listening task (Harris, 2014). Evidence from experimentally socially excluded individuals support the notion that they have difficulty in attentional control (Baumeister, DeWall, Ciarocco & Twenge, 2005): those who were socially excluded were unable to self-regulate effectively. For instance they were more likely to consume unhealthy snacks, less likely to drink a healthy beverage with a bitter taste, and gave up faster during a frustrating task compared to their socially included counterparts. This suggests that similar attention difficulties reported for lonely people were also found among excluded people after manipulation of inclusion/exclusion.

All of these studies using different methodologies indicate that loneliness is associated with heightened attention to (negative) social information. Only one study using a child sample (i.e. Qualter et al, 2013b: study 3) has directly assessed the hypothesis that hypervigilance to social threat leads to attentional biases as part of Cacioppo and Hawkley's (2009) loneliness model.

(b) Evidence for perceptual biases

Feelings of loneliness may cause the lonely person to perceive and interpret the social situation differently and/or negatively compared to non-lonely people. Typically, evidence for perceptual biases has come from studies in which participants are asked to make conversations with a familiar or non-familiar person in dyadic interactions and rate themselves and their conversational partners on a number of behaviours. Jones, Sansone and Helm (1983) found that lonely adults rated themselves more negatively and expected their conversational partners to rate them more negatively then non-lonely adults, when asked to evaluate a conversation undertaken with a stranger. Similarly, when asked to evaluate conversations with a friend (known for a minimum of 6 months), lonely adults negatively evaluated their communication quality as lower and gave more negative ratings for their own relationships overall (Duck, Pond & Leatham, 1994). These studies suggest that lonely adults are more focused on negativity in social encounters, but they do not directly measure whether lonely people perceive conversations as socially threatening events. Similarly, lonely children and adolescents interpret social situations negatively (Qualter & Munn, 2002; Vanhalst, Luyckx, Scholte, Engels & Goossens, 2013).

Empirical evidence also indicates that lonely people are characterised by attributional biases. Lonely adults perceive or anticipate rejection, but are not necessarily rejected by others (Jones, Freemon & Goswick, 1981). Likewise, lonely children and adolescents are sensitive to rejection (Qualter et al, 2013b: study 1 & 2) and show increased fear of negative evaluation (Jackson, 2007). In addition, lonely individuals make more self-derogatory attributions (Cutrona, 1982; Snodgrass, 1987) and are more likely to blame themselves when explaining the causes of social exclusion in comparison to non-lonely people

(Qualter & Munn, 2002; Solano, 1987). Lonely adults perceive the social world as more threatening (Cacioppo et al, 2000) and interpret their daily hassles as more stressful then non-lonely adults (Hawkley et al, 2003).

(c) Evidence for behavioural biases

Cacioppo and Hawkley's (2009) model predicts that hypervigilance for social threats and negative cognitive biases cause some lonely people to behave in certain ways that undermines social interactions such as pushing people away or withdrawing socially from the social environment (Cacioppo et al, 2014). Empirical evidence suggests that lonely people differ in their behaviour in the social world, but whether these cognitive biases lead to behaviour deficiencies have not been examined. Lonely children have been found to show different behaviours in social situations ranging from shyness and social withdrawal to hostile and aggressive behaviours (Cassidy & Asher, 1992; Coplan et al, 2007; Qualter et al, 2013; Qualter & Munn, 2005). Lonely children and adolescents compared to their peers use more passive coping strategies (e.g. avoidance) instead of active coping strategies (Jobe-Shields et al, 2011; Vanhalst et al, 2012).

Similarly, lonely adults are found to be less attentive to their partners during conversations (Jones, Hobbs & Hockenbury, 1982), which signals to their conversational partners a lack of interest or unwillingness to listen to them. Additionally, lonely adults are less inclined to take social risks (Moore & Schultz, 1983) and use more social avoidance strategies (Nurmi, Toivonen, Salmela-Aro & Eronen, 1997). Lonely adults compared to non-lonely adults are less likely to actively cope or seek emotional/instrumental support in everyday life (Cacioppo et al, 2000; Steptoe et al, 2004), suggesting that they withdraw from the social environment. The evidence for behavioural biases amongst lonely adults is very limited and further research is needed to evaluate these behavioural biases using stringent observational methodology.

(d) Evidence for differences in brain functioning and brain structure

Loneliness is reflected in the way the brain processes visually presented information. Cacioppo et al., (2009) found a brain signature that characterised lonely adults in an fMRI study where participants viewed pictures showing social/non-social or pleasant/unpleasant scenes from the International Affective

Picture System (IAPS). The authors found that lonely individuals showed less activation of the ventral striatum (the reward system in the brain) to pleasant social pictures of people than objects; non-lonely individuals showed greater activation to pleasant social pictures than objects in the same area. In contrast, lonely adults showed greater activation of the visual cortex in response to unpleasant social pictures of people than objects. This suggests that lonely people are more attentive to the distress of others, while non-lonely adults showed greater activation of the temporo-parietal junction (related to emotion processing of others). To date, only the above study has been conducted to identify how lonely people processes visual information in the brain. However, the fMRI study did not directly assess the hypervigilance to social threat hypothesis, and only looked at basic unpleasant IAPS pictures with no depiction of social interactions or social relationships (i.e. social threat depicted as negative social relationships or social interactions).

In general, evidence indicates that loneliness is related to differences in brain structure. Kong et al., (2014) found that lonely Chinese adults had more grey matter volume in the left dorsolateral prefrontal cortex (DLPFC), a brain area that has been implicated in emotional regulation and attentional processes. Kanai et al., (2012) found that lonely individuals have less grey matter in the left posterior superior temporal sulcus (pSTS), which plays a functional role in processing social cues. Based on this evidence, the authors argue that lonely individuals are likely to have difficulty in basic social perception. A follow-up to that study revealed that loneliness was specifically linked to difficulty in understanding the eye-gaze of others, thus confirming the role of pSTS in loneliness. However, the eye-gaze task did not measure a perception of threat to social cues (i.e. hypervigilance), and the task only investigated the ability to understand eye-gaze generally and not eye-gaze related to emotion. To date, the neuroimaging research in loneliness is very sparse and only conducted in adult samples.

Summary: loneliness and cognition

Empirical evidence from studies examining the cognitive biases in loneliness has consistently supported the view that lonely adults show a heightened response to negative social information. However, none of the above studies have directly and systematically assessed whether lonely adults are hypervigilant to social threats and whether this alertness causes cognitive biases which ultimately lead to poor health. In addition, the research on how lonely adults process social threat information in the brain is very limited.

Cognitive models from a related literature

Cacioppo and Hawkley's (2009) model proposes that loneliness is associated with an implicit hypervigilance to social threats in the social environment which leads to cognitive biases that undermine the opportunity to maintain positive social relationships. Relevant models from the social exclusion and social rejection literature, however, suggest that when an individual's innate need to belong (e.g. Baumeister & Leary, 1995) is not met, the individual may extensively monitor the environment for social cues to facilitate social opportunities. It is important to note that social exclusion is different from the construct of loneliness (Leary, 1990).

The Social Monitoring System (SMS)

The SMS (Gardner, Pickett & Brewer, 2000; Gardner et al, 2005; Pickett, Gardner & Knowles, 2004) proposes that when belonging needs are unmet (i.e. due to social exclusion) the individual monitors social information that lead to social opportunities. Specifically, once the SMS is activated, people monitor the social environment for both positive and negative social cues that encourage behaviours to regain social inclusion and prevent further rejection. This is thought to be an adaptive response to social exclusion because individuals process positive and negative social cues. Prior research focusing on the SMS has found that following acute rejection, individual's showed selective memory for social events (Gardner et al, 2000), and those scoring high on a need to belong scale were more accurate at identifying vocal tones and facial emotions (Pickett et al, 2004).

Pickett et al (2004) imply that individuals high on loneliness show enhanced levels of social monitoring and extensively scan the social environment for social cues (positive and negative) that could lead to more social opportunities. To date, only one study has examined the SMS in lonely people using a memory paradigm. That study found that lonely adults were more likely to remember social events compared to non-lonely adults (Gardner et al, 2005). However, whether lonely people attend to positive and negative social cues in the environment has not been examined.

The Rejection Sensitivity Model (RSM)

Similar to that proposed by Cacioppo and Hawkley (2009) for lonely people, the RSM (Downey & Feldman, 1996) argues that individuals with high rejection sensitivity scores are likely to focus on social exclusion cues in the social environment to avoid further rejection (i.e. focusing on self-preservation). The construct of rejection sensitivity is related to a bias in which individuals readily expect and perceive rejection from others (even in ambiguous situations) based on prior experiences of rejection. Prior research on the RSM has found that those scoring high on rejection sensitivity were more attentive to social threat words in an emotional stroop task (Berenson et al, 2009) and detected more negative emotions from video footage (Romero-Canyas & Downey, 2013), compared to those scoring low on rejection sensitivity.

The social threat conceptual model

Cacioppo and Hawkely's (2009) loneliness model suggest that lonely people are hypervigilant to *social threat* which leads to a cascade of cognitive and physiological reactions. However, the authors do not explicitly indicate whether they are referring to a hypervigilance to all social threats or to a specific type of social threat. Kemeny's (2009) model defines social threat as a threat to one's social status such as social devaluation, discrimination or rejection. Social status, value and acceptance are thought to be fundamentally important factors in maintaining social connections for humans; situations that threaten these factors adversely cause behavioural, psychological and biological changes. The current thesis draws on the ideas that social threat can be conceptualised as rejection. It is possible that lonely people may be on high alert for specific social threats (e.g. rejection), instead of more generalized threats such as negative social information in the social world.

Examining the hypervigilance to social threat hypothesis

Hypervigilance to (social) threat can be viewed as a cognitive process and is referred to as an attentional bias or selective attention to threat stimuli compared to neutral stimuli (Mogg & Bradley, 1998). Four different paradigms have been used to examine hypervigilance in the cognitive literature: (1) in emotional stroop tasks, threat and neutral words are written in different ink colours and participants are asked to state the colour while ignoring the sematic content. Higher reaction times to threat words are indicative of a hypervigilance response. This paradigm has been criticised because higher reaction times could either infer enhanced attention or avoidance of threat (Bogels & Mansell, 2004; Fox et al 2001); (2) the dot-probe task appears to be a more valid measure of selective attention. In this paradigm, two words or faces are presented simultaneously for a brief duration, the stimuli is then replaced with probes and the participant is asked to indicate which stimuli was replaced with the probe. Quicker response times at indicating the probe replaced the threat stimuli suggest an attentional bias to threat stimuli; (3) visual search tasks are a more direct measure of selective attention as they incorporate spatial measures. Participants are asked to detect threatening stimuli in an array of neutral stimuli and vice versa. Quicker response times to threat detection in neutral stimuli indicate a hypervigilance response (Cisler & Koster, 2010); (4) the most direct measure of attentional bias to date is the use of eye-tracker technology. Eye movements are recorded in real time and overt attention is measured during free viewing or visual search tasks. Sudden eye movements and durations (dwell time) of fixating on the threat stimuli are used as indicators of attentional biases to threat (Bogels & Mansell, 2004).

Use of eye-tracker technology

Eye-tracker technology is an excellent tool in research for studies examining information processing as it directly assesses selective attention continuously across long periods of time (Hermans, Vansteenwegen, & Eelen, 1999). It examines both early (hypervigilance) and late (avoidance) processing of attention, which is a more accurate measure of selective attention, compared to other cognitive tasks (i.e. emotional stroop, dot probe and visual search tasks) that provide only a snapshot of attention in most cases. Additionally, eye-tracker measures are more proximal to attention then manual button presses in cognitive tasks and do not rely on reaction times measures that limit the use of cognitive tasks at measuring attention. Therefore, the use of the eye-tracker provides a naturalistic assessment of selective attention, overcomes the inherent problems of other cognitive paradigms, and fully inform researchers about the time course and components of attention (Armstrong & Olatunji, 2012).

In the eye-tracking literature, there are different components of attention processing to threat stimuli: (1) initial vigilance and maintenance (i.e. hypervigilance) relates to the speed and ease (orientation) of attention to threat (Armstrong & Olatunji, 2012), (2) disengagement difficulties refers to attention being captured by the threat stimuli and suggests an impairment in switching from threat cues to other stimuli (Buckner, Maner, & Schmidt, 2010), and (3) attentional avoidance refers to orienting attention away from threat (Lange et al., 2011). The initial vigilance and maintenance pattern of processing is thought to be automatic, unintentional and outside voluntary control, while the latter attention processes (attentional avoidance, disengagement difficulties) is thought to be strategic, intentional, under voluntary control and occur on a later timescale during extended viewing (Cisler & Koster, 2010).

With regards to the above distinctions between components of attention, previous eye-tracker studies (i.e. Buckner et al, 2010; Hermans et al, 1999) recommend the use of time-blocks to assess the patterns of attention deployment. Time-blocks also referred to as epoch-related measures are derived from fixation durations to stimuli within a certain time-window (Rinck & Becker, 2006). Initial vigilance is demonstrated in the first 1 second and attentional avoidance demonstrated in durations ranging from 3 seconds to 60 seconds (Armstrong & Olatunji, 2012). Event related measures, for instance the location of the initial fixation and duration of the first fixation, are used to assess the initial vigilance to threat stimuli (Garner, Mogg & Bradley, 2006).

In addition, eye-tracker technology has been used to identify specific processing biases to social threat stimuli that may be involved in the maintenance of certain disorders such as social anxiety and depression (Wieser, Pauli, Weyers, Alpers, & Mühlberger, 2009). Social anxiety is characterised with an initial vigilance and maintenance attention processing bias, while depression is characterised by biases in extended viewing (Armstrong & Olatunji, 2012).

Recently in the loneliness literature, Goossens (2012) suggested a necessity for research investigating attentional biases in loneliness using eye-tracker technology; Goossens argued that there is a need to understand whether the hypervigilance for social threat hypothesis for loneliness could be explained by visual attention deployment. To date, only one study has examined the visual attentional biases to social threat cues in lonely children using eye-tracker methodology. Qualter et al., (2013b: study 3) found that loneliness was characterised by an attentional bias consistent with disengagement difficulties to real life footage of socially threatening scenes. However, this study was only conducted using a child sample and a different attention processing style to social threat stimuli may be apparent for lonely adults. This is because significant cognitive development occurs during childhood to adulthood (Anderson, 2002; Best & Miller, 2010) and attention processing may be different between children and adults once their cognitive skill has matured.

Gaps in loneliness research – What's missing from the literature?

The focus of this thesis is on examining the cognitive component of the loneliness model proposed by Cacioppo and Hawkley (2009). Within that model, the hypervigilance to social threat hypothesis has not been directly examined in lonely adults.

Association between loneliness and attention to social threat (i.e. social rejection)

The model of loneliness proposed by Cacioppo and Hawkley (2009) sees lonely people as hypervigilant to social threats in the environment; being lonely influences how people perceive their social world. Specifically, past research suggests that lonely people are focused on issues of rejection and social exclusion (Jones & Carver, 1991; Jones et al, 1981; Sloan & Solano, 1984). This means that social threat for lonely people may be conceptualised as threats that are linked to social rejection or social exclusion.

In support of Cacioppo & Hawkley's model, evidence shows that lonely people use threat-related cognitions to explain their social world. For example, lonely adults report feeling more threatened in social situations and worry that others will ignore or reject them (Cacioppo et al, 2000; Jones et al, 1981); they also report higher levels of interpersonal stress than non-lonely people (Doane & Adam, 2010). In addition, lonely individuals more often blame themselves when explaining the causes of social exclusion compared to non-lonely people (Qualter & Munn, 2002; Solano, 1987).

Interestingly, while lonely people have a bias to use threat-related cognitions, but these do not match their social experience. Empirical evidence suggests that lonely people perceive or anticipate rejection, but they are not necessarily rejected by others (Jones et al, 1981; London, Downey, Bonica & Paltin, 2007; Qualter & Munn, 2005).

Research also shows attention and memory biases in lonely people. Lonely adults show greater recall for social events compared to non-lonely people (Gardner et al, 2005), suggesting that social events are particularly salient to them. However, in a classic Stroop test, negative social words (e.g., rejected, alone, disliked) created greater interference for lonely than non-lonely adults (Egidi et al, 2008); there were no differences on positive social words. This finding is consistent with Cacioppo and Hawkley's (2009) theory because it suggests that loneliness intensifies feelings of potential threat: loneliness appears to prime people to look for negative social events in the environment. Further support comes directly from Cacioppo et al., (2009) who showed loneliness increases attention to negative social information. They report that lonely people had fewer neural responses to pleasant social stimuli, with heightened neural activation in the visual cortex during the viewing of unpleasant social pictures, thus, indicating lonely adults have greater visual attention to these stimuli.

Although these latter studies provide important information about attentional biases for social threat among lonely people, the assessment is incomplete because it does not look at visual processing of social threat information. There is a necessity for research investigating attentional biases in loneliness using eye-tracker technology to complete the picture of cognitive biases of lonely people (Goossens, 2012); there is a need to further examine whether the hypervigilance for social threat hypothesis for loneliness extends beyond negative cognitive appraisals of the social world to visual attention deployment.

Loneliness and cognition

The studies in this thesis aim to directly examine the hypervigilance to social threat hypothesis put forward by Cacioppo and Hawkley (2009) in their model of loneliness. It is important to directly assess whether lonely people are hypervigilant to social threats because this forms the basis of the loneliness model and is proposed to perpetuate a series of interacting factors, which leads to poor health. If this is not the case, then Cacioppo and Hawkley's model of loneliness has to be re-examined and updated. Also, it is important to test the hypervigilance to social threat hypothesis using different methodologies and experimental designs to rule out the possibility that any such findings are not an artefact of one particular method, and to demonstrate there is a distinct pattern of hypervigilance associated with loneliness. Further, to date there is only one study that directly assesses the hypervigilance to social threat hypothesis using eye-tracker methodology and this used socially rejecting stimuli depicted as social threats (Qualter et al, 2013b). The authors argue that social threat may be a specialised bias to social rejection, but it is possible that lonely people show a generalised hypervigilance to negative emotions depicted as facial expressions that puts them on a heightened alert in their everyday lives when interacting in the social environment; as of yet no empirical studies has investigated this claim. Consistent with this view, there has been little research in the literature looking into the visual attentional processing of lonely adults and how social threats are processed by the brain; it may be that lonely people are constantly on the look out for social threats.

The research gaps in the research literature can be summarized as follows:-

- Limited research studies examining the hypervigilance to social threat hypothesis
- One study on visual attention processing of social rejection stimuli in children
- No research study examining visual processing of emotional information
- Some evidence of conceptualisation of social threat as a specific bias
- No research study in the loneliness literature examining how social threats are processed in the brain

Further research is needed to examine these gaps in the literature in order to do the following:-

- Directly examine the hypervigilance to social threat hypothesis

- Investigate the visual attention processing to social rejection stimuli in adults
- Examine the visual attention processing of emotional information
- Conceptualisation of *social threat* (specific bias or general bias)
- Processing of social threats in the brain (discussed in chapter 5 and 6 of the thesis)

Summary of present thesis

The research aims of the present thesis are discussed in the context of the loneliness literature to date in the following chapter (Chapter 2). Subsequent chapters (3 and 4) include empirical studies that address the gaps in literature as outlined above. Chapter 5 outlines a short theoretical introduction to neuroimaging techniques followed by chapter 6 that includes the empirical study based on neuroimaging methodology. Chapter 7 provides a summary of all the research findings, a discussion of the impact these results will have on loneliness research and will provide a discussion regarding the next step in loneliness research.

Chapter 2: Present Thesis in the Context of Loneliness Research

Cacioppo and Hawkley's (2009) model postulates that lonely people are hypervigilant to social threats in the social environment (this will be described as the hypervigilance to social threat hypothesis throughout the thesis), but for some lonely people this causes faulty cognitive biases that undermine the opportunity to develop positive social relationships. Empirical evidence supports this view that loneliness is associated with cognitive biases.

Evidence for attentional biases in lonely people

Lonely people show greater attention to negative social information examined using different cognitive methodologies. In a modified emotional stroop task, where participants were asked to name the colour of threat and positive words written in different ink colours, lonely adults showed greater interference to negative social words (disliked, alone and rejected) compared to non-lonely adults (Egidi et al, 2008). Similarly, findings from an fMRI study found that lonely adults have greater neural responses (specifically in the visual cortex) to negative social pictures and reduced neural responses to positive social pictures (Cacioppo et al, 2009). Furthermore, lonely adults show poorer attentional regulation than non-lonely adults (Cacioppo et al, 2000) during a dichotic listening task, suggesting that feeling lonely decreases attention and causes more distractibility to the task at hand. However, lonely adults show greater recall of social events (both positive and negative) compared to non-lonely when asked to read diary extracts from others (Gardner et al, 2005), suggesting that social events are important to them. Recently, lonely children showed a difficulty in disengaging from social threat stimuli depicted as social rejection using eye-tracker methodology (Qualter et al, 2013b).

Evidence for perceptual biases in lonely people

In line with Cacioppo and Hawkley's model, loneliness is associated with negative social perceptions in the social world. Lonely adults report feeling more threatened in social situations (Cacioppo et al, 2000; Jones et al, 1981; Jones et al, 1983). Lonely adults also perceive or anticipate rejection, but they are not necessarily rejected by others (Jones, 1990; Jones & Carver, 1991; Jones et al, 1981; Jones et al, 1983; Sloan & Solona, 1984). Lonely people experience more stress in everyday life rating their daily hassles as more stressful than non-lonely people (Hawkley et al, 2003) and report higher levels of interpersonal stress (Doane & Adam, 2010). In addition, lonely individuals make more self-derogatory attributions (Cutrona, 1982; Snodgrass, 1987) and are more likely to blame themselves when explaining the causes of social exclusion in comparison to non-lonely people (Solano, 1987).

Taken together, these studies suggest that lonely adults show a heightened response in overall attention and perception to negative social information in the environment. However, most research on the cognitive biases of lonely adults has focused on the attentional/perceptual biases and does not examine the hypervigilance to social threat hypothesis directly. Also, the extent to which lonely adults attend to emotional information is very under-researched. An empirical study shows individuals' reporting fewer close friendships were more accurate at identifying emotions from faces and showed greater attention to emotional vocal tones (Gardner et al, 2005), with the implication that loneliness may be associated with attention to emotional expressions. Another gap in the literature relates to the visual attentional processing of lonely adults. It may be that lonely adults are constantly on the look out for negative social information (i.e. social threats) or on the look out for social information. This thesis aims to redress these gaps in the loneliness research.

Aims of present thesis

The present thesis aims to provide a systematic examination of the hypervigilance to social threat hypothesis in loneliness using adult samples and addresses the previously identified gaps in the literature (see chapter 1) in the empirical chapters that follow. It is important to directly examine the hypervigilance to social threats hypothesis in lonely adults because Cacioppo and Hawkley (2009) argue that this implicit hypervigilance for social threats triggered by feelings of loneliness initiates a cycle of inter-related factors (i.e. cognitive biases) that ultimately leads to negative health outcomes. If this is not the case, some other mechanism may be involved in the association between feelings of loneliness and poor health such as stress. Thus, a re-evaluation of the loneliness model may be needed. To date, only one study directly examines the hypervigilance to social threat hypothesis and they examine this in lonely children (aged 8 to 12 years) using eye-tracker methodology (Qualter et al, 2013b: study 3). The authors found support for Cacioppo and Hawkley's (2009) theory: very lonely children were unable to relocate attention (i.e. implicit hypervigilance) from social threat stimuli in comparison to non-lonely children in the initial four seconds of viewing time. This thesis aims to examine the hypervigilance to social threat hypothesis in lonely adults, which has been currently under researched in the loneliness literature.

Specific goals of empirical chapters

Chapter 3 examines the visual attention biases of lonely adults which have not been researched in the loneliness literature. The empirical study uses real-life video footage of socially threatening scenes depicted as social rejection or social exclusion and eye-tracker methodology to determine visual responses to those stimuli. To date, only one eye-tracker study has examined visual attention biases of lonely children when viewing socially threatening scenes (Qualter et al, 2013b: study 3), but the present study investigates this in lonely adults.

Chapter 4 focusses on the cognitive biases of lonely adults to static images. Specifically, it investigates whether lonely adults are hypervigilant to social threats depicted as emotional expressions and static scenes. The chapter extends and builds on the work from chapter 3. This chapter is divided into four studies (studies 2 - 5) that examine directly the hypervigilance to social threat hypothesis in loneliness. Study 2 investigates the hypothesis in relation to lonely adults' processing of emotion and eye-gaze of others as a direct measure of threat perception. In support of this, it has been suggested that loneliness is linked to a deficit in processing basic social cues (Kanai et al, 2012). Study 3 looks at the visual attentional biases of lonely adults to basic emotional faces (happiness, anger, fear and neutral expressions) to understand how loneliness is associated to the processing of emotions. Findings from Gardner et al's (2005) study show that those who reported having fewer close friends were more attentive to emotional vocal tones. Study 4 expands on these findings and examines the visual attention biases to emotional facial expressions as presentation of faces in a group context, with the idea that lonely adults are hypervigilant to threats in a crowd. Study 5 investigates the visual attentional biases of lonely adults to static scenes of social threat linked to exclusion and rejection, physical threat, positive (social) and neutral pictures. Study 5 also examines whether lonely adults attend differently to social threats in comparison to social stimuli/physical threat stimuli.

Chapter 5 provides a theoretical and methodological overview of neuroimaging techniques with a focus on electroencephalogram (EEG) technique. The chapter concludes with a rationale for conducting study 6 as described in chapter 6 that examines loneliness and neural responses to social threat stimuli. Study 6 is an expansion of study 5 that examines whether visual attention biases in lonely adults are consistent with the hypervigilance to social threat hypothesis for threats that are specifically linked to social rejection and/or social exclusion stimuli. Study 6 focuses on examining the specific brain neural responses in lonely adults when viewing social threat (rejection) stimuli. Previous research from an fMRI study conducted by Cacioppo et al. (2009) found that lonely adults showed greater activation of the visual cortex in response to unpleasant social pictures of people than objects. This suggests that lonely people are more attentive to distressing pictures of people. Non-lonely adults showed greater activation of the temporo-parietal junction (related to emotion processing of others). The unpleasant social pictures used in that study did not depict social relationships or social interactions, so study 6 addresses whether loneliness is associated with specific brain responses when processing pictures of social interactions and social rejection (i.e. social threats).

Study methodology and research populations

The empirical chapters in this thesis use different methods to directly examine the hypervigilance to social threat hypothesis in lonely adults. This section outlines the methods used for each study.

Study 1

Study 1 used eye-tracker methodology to assess visual attention to video footage. In this study, loneliness was the predictor variable and the percentage of fixation time on the socially threatening stimuli across 8 time intervals ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, and 4000ms was the criterion variables. The participants' level of loneliness was assessed using the UCLA loneliness scale (Russell, 1996). This measure is used because it taps into the emotional feelings of loneliness, which the study aimed to assess. The video footage used in this study shows social interactions of adolescents during their lunch or free period and was taken from schools and colleges in England. The video stimuli included scenes showing both positive social behaviour (i.e. smiling, encouragement in the form of nodding) and socially threatening behaviour (i.e. lone individual being ignored by a group of peers, discordant body posture). The socially threatening scenes were chosen to show instances of social rejection and the positive social scenes were chosen to show positive interactions. The video footage shown to participants in this study was the same video stimuli previously used in a study by Qualter et al (2013b) that assessed visual processing of lonely children. The same stimuli were used across both studies in order to make a direct comparison on whether the way lonely children process socially threatening information differs to the way lonely adults process this same information.

In this study, undergraduate students were recruited using an opportunity sample. The age range was narrowed to 17 to 19 years. This was done because the study aimed to examine attention processing in young adults/adolescents and compare the findings to a child sample. Regression analyses were used to analyze the results and examine the association between loneliness and attention to social threat stimuli. The UCLA loneliness score was the predictor variable and the percentage of fixation time on the social threat stimuli across the 8 time-blocks were the criterion variables. The regression analytic strategy was adopted initially, instead of using group analyses (i.e. ANOVAs), because within the loneliness literature there is not a cut-off score for how to group scorers on high and low loneliness. Therefore, regression analyses were used in the analyses to examine loneliness on an individual level.

Study 2

Study 2 used a cognitive paradigm to capture initial emotional and eye-gaze processing by examining subjective responses to stimuli. The predictor variable was the mean loneliness score and the criterion variables were the mean proportion of subjective responses to emotional stimuli across five different viewing angles. Loneliness was measured using the UCLA loneliness scale (Russell, 1996). Participants' level of social anxiety was assessed using two measures; The Brief Fear of Negative Evaluation Scale (BFNE; Leary, 1983a) and the Interaction Anxiousness Scale (IAS; Leary, 1983b; Leary & Knowalski, 1993). In addition, participants' level of depressive symptomology was assessed using the Center for Epidemiologic Studies Depression Scale (CES-D; Rudloff, 1977). Social anxiety and depression were included in the analyses as control variables because these constructs are highly correlated with loneliness and cognitive biases (see below for further details). The stimuli used in this study include faces of 12 actors (6 males and 6 females) expressing happiness or anger with their gaze fixated centrally or at different angles to the left/right. Participants were asked to decide whether the face was looking at them or not. These stimuli were selected because it assesses both the emotional expression of the face and the eye-gaze perception in one cognitive paradigm. The task also examined the participants' subjective response to the faces instead of the more general question regarding the direction of the face (i.e. is the face looking in the centre or left/right?)

Studies 3, 4 and 5

Studies 3, 4 and 5 assessed selective attention to visual stimuli using eye-tracker methodology to static images. The use of eye-tracker technology allows an examination of sustained visual processing with the ability to discriminate between early and later processing of attention making it an excellent tool in research in comparison to other visual attention tasks (Bogels & Mansell, 2004).

Study 3 assessed the visual attentional biases of lonely adults to basic emotional expressions (anger, happiness, fear and neutral). Loneliness was the predictor variable and the percentage of fixation time across 16 time blocks (each 500ms in duration) for each emotional expression were the criterion variables. Loneliness, social anxiety and depression was assessed using the same measures described in study 2. The stimuli used in this study were chosen to depict the universal emotional expressions and were selected from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt & Öhman, 1998). The angry and fearful emotional expressions were selected because these emotions are classed as socially threatening cues. The facial expression depicting happiness was chosen to reflect a positive emotion, while the neutral expression was chosen because it reflects a non-emotional state. A

2 by 2 matrix was used to present the four emotional expressions simultaneously to participants. Each matrix of pictures was randomized such that any of the four emotional expression could appear in any location within the 2 by 2 matrix (i.e. top left, top right, bottom left, bottom right). This randomization strategy increases the reliability and makes for a stronger design of the overall study.

Study 4 assessed the visual attentional biases of lonely adults to emotional expressions presented in a group context (i.e. face in the crowd stimuli). Loneliness was the predictor variable and the percentage of overall fixation time on the happy and angry faces in the seven ratios of the crowd stimuli were the criterion variables. Participants' level of loneliness, social anxiety and depression was assessed using the same measures described in study 2. The stimuli were selected from the KDEF database (Lundqvist, Flykt & Öhman, 1998). A total of 16 photographs were presented in a 4 by 4 matrix that included both happy and angry emotional expressions. Each matrix included a different ratio of happy to angry faces (I.e.14 happy:2 angry, 12 happy:4 angry, 10 happy:6 angry, 8 happy:8 angry, 6 happy:10 angry, 4 happy:12 angry, 2 happy:14 angry). Within each matrix, the happy and angry emotional expressions were randomized such that any of the faces could appear in any of the 16 picture locations and each actor only appeared once. The face in the crowd paradigm was chosen for this study because participants typically show an attentional bias for a particular emotion when presented. Findings suggest an anger superiority effect for this stimuli such that participants focus their attention towards the angry faces when the crowd stimuli is overly populated with happy faces (i.e. 14 happy:2 angry crowd type).

Study 5 assessed the visual attentional biases of lonely adults to visual scenes (social threat, physical threat, positive social and neutral images). Loneliness was the predictor variable and the percentage of fixation time across 16 time blocks (each 500ms in duration) for each picture type were the criterion variables. Loneliness, social anxiety and depression were assessed using the same measures described in study 2. The stimuli set was selected from the International affective picture system (IAPS) database (Lang, Bradley & Cuthbert, 2008). Example stimuli were as follows: a young adult being rejected by a group of peers as social threat pictures; a gun and violence depictions as physical threat pictures; a family gathering as socially positive pictures; images of the sky and a field as neutral pictures. The social threat pictures were chosen to show instances of social rejection or sadness and the physical threat pictures were chosen to show a threat that evokes a fear response. The social positive pictures were chosen to show positive social interactions, whilst the neutral pictures were chosen because they have been shown to produce neutral ratings. A 2 by 2 matrix was used to present the four visual scenes simultaneously to participants. Each matrix of pictures was randomized such that any of the four visual scenes could appear in any location within the 2 by 2 matrix (i.e. top left, top right, bottom left, bottom right)

For studies 2, 3, 4 and 5, students and staff from the university were recruited using an opportunity sample via online advertisements. The age range was narrowed to 18 to 30 years in the analyses. The cut-off for age was 30 years because prior evidence suggests that age impacts cognitive ability in cognitive tasks (Ebner, He & Johnson, 2011; Hartshorne & Germine, 2015; Verhaeghen & Salthouse, 1997). Also, the cut-off of 30 years was used in studies 3, 4 and 5 because these studies assessed eye movements using eye-tracker methodology. Age-related changes in performance on eye-movements tasks have been found. Specifically. Munoz, Broughton, Goldring and Armstrong (1998) reported that the age group of 20 to 30 years had the fastest eye movements compared to young children and elderly adults.

Regression analyses (linear and quadratic) were used to analyze the results for studies 2 to 5. Initially, loneliness was the predictor variable in these analyses and the criterion variable were the proportion of subjective responses (study 2), percentage of fixation time on emotional faces (study 3), percentage of fixation time on face in the crowd stimuli (study 4), and the percentage of fixation time on visual scenes (study 5). Following these analyses, social anxiety and depression were controlled in the analyses using a standardized residual of loneliness. This residual controlled for both social anxiety and depression, and was used as the predictor variable in the analyses of studies 2 to 5. The aim of these analyses was to examine the unique association between loneliness and attention processing, whilst controlling for both social anxiety and depression.

Study 6

Study 6 (chapter 6) used non-invasive EEG methodology to measure neural responses to visually presented information. The EEG records electrical activity of the brain by attaching multiple electrodes to the scalp using a net or cap. A detailed overview is given in chapter 5.

A 2 x 2 x 2 mixed design was used in the behavioural component of this study. Loneliness was the independent variable (lonely, non-lonely) and the subjective valence ratings and reaction time (ms) for the type of stimuli (social/non-social) and nature of stimuli (threat/non-threat) were the dependent variables. The stimuli were selected to reflect this and images were classed into one of four categories (social threat, non-social threat, non-social threat, non-social non-threat). The stimuli were selected from the IAPS database (Lang, Bradley & Cuthbert, 2008). Example stimuli were as follows: a crying boy and a child being rejected by his peers as social threat pictures; a series of snake pictures as non-social threat pictures; people cooking together and people walking in a crowd as social non-threat pictures; a landscape and a book as non-social non-threat pictures. The social threat pictures were chosen to present instances of social rejection by others or sadness and non-social threat pictures showed a biological threat that produces a fear response in the majority of individuals; the social non-threat pictures were chosen to present social interactions, while non-social non-threat pictures were pictures of objects and scenery that have been shown to produce neutral ratings.

A 2 x 2 mixed design was used in the EEG component of this study. The level of loneliness (lonely, non-lonely) was the independent variable and the spatial and temporal domain of the neural responses (microstates) to the social threat and non-social threat pictures were the dependent variables. Loneliness was measured using the UCLA loneliness scale (Russell, 1996). Participants' level of social anxiety was assessed using the Interaction Anxiousness Scale (IAS; Leary, 1983b; Leary & Knowalski, 1993). In addition, participants' level of depressive symptomology was assessed using the Center for Epidemiologic Studies Depression Scale (CES-D; Rudloff, 1977).

ANOVA analyses were used to analyse the behavioural data, with the level of loneliness as the independent variable and valence ratings/reaction time to the type of image as the dependent variable. Following these analyses, social anxiety and depression were controlled in the analyses by including them as covariates. A new analytic tool (see Chapter 5) was used to analyse the

EEG/ERP data, with loneliness as the independent variable and the spatial and temporal domain of the microstates of the social threat and non-social threat images as the dependent variables. Unlike the behavioural data analyse, it was not possible to control for social anxiety and depression in the ERP data analyses by adding these variables as covariates. This was because the ERP data needed to be grouped into either a lonely or non-lonely group in order to conduct analyses based on the microstate approach and use source localization techniques, which provides detailed information on the spatial and temporal dynamics of the brain. In addition, regression analyses were not used in this study because classifying loneliness into groups was appropriate for the new analytic tool used for the ERP data analyses. Specifically, the new analytic tool has not been adapted to include suitable regression techniques to analyse the outcomes.

Studies in the thesis

Taken together the present thesis provides a systematic examination of the hypervigilance to social threat hypothesis in adults using cognitive paradigms, eye-tracker and EEG methodology, thus indicating that any loneliness effects found are not due to any one method and that there is a distinct pattern of hypervigilance associated with loneliness. The findings of the thesis have both theoretical and practical implications for the loneliness literature which are discussed in chapter 7.

All studies described in the thesis used a predominantly student sample. Studies 1 to 5 use a UK sample at the University of Central Lancashire open to all staff and students from all subject divisions and open to any age from 18 years and above. Study 6 uses a US sample at the University of Chicago open to all staff and students and open to any age from 18 years and above. The same participants took part in studies 3, 4 and 5. Studies 3 to 6 used an online pre-screening loneliness measure in an attempt to recruit extreme loneliness scorers at both end of the high/low spectrum and obtain a wide distribution of scorers

Presentation of results in the thesis: chapter 4 & behavioural results in chapter 6

Social anxiety and depression have been examined in the studies included in chapter 4 and behavioural results in chapter 6 of this thesis. This is because loneliness is highly correlated and closely related with these constructs. However, it has been argued that depression (e.g. Cacioppo et al, 2010; Lasgaard, Goossens & Elklit, 2011) and social anxiety (e.g. Jones et al, 1990) are distinct constructs from loneliness. Additionally, social anxiety and depression have been examined in relation to the hypervigilance to social threat hypothesis using cognitive paradigms and eye-tracker methodology (e.g. Armstrong & Olatunji, 2012) so it is important to control for depression and social anxiety in studies which examine loneliness. But, controlling for social anxiety and depression in the analyses may reduce/lose the negative affect associated with loneliness, in effect reducing the construct validity of loneliness.

Recently, researchers in the loneliness field have debated whether controlling for social anxiety and depression in research studies is appropriate. A number of researchers (e.g. Lodder, Scholte, Clemens, Engels, Goossens & Verhagen, 2015; Vanhalst, Gibb. & Prinstein, 2015) argue the necessity to control for the negative affect associated with loneliness. They suggest that loneliness is a core feature of both social anxiety and depression, and removing this variance leaves “pure” loneliness. One could argue, however, that controlling for social anxiety and depression is not appropriate because the negative affect that loneliness shares with social anxiety/depression is central to the concept of loneliness and removing the negative affect means the remaining variance is of poor construct validity.

This thesis takes the view that even though it is important to control for the negative affect associated with loneliness in cognitive studies in detangling the shared variance of individual components; it is essential that any practical and theoretical implications are based on loneliness with the associated negative affect because they are conceptually overlapping constructs and such variance cannot be removed. Taking this into account, the current sets of studies in chapter 4 and behavioural results in chapter 6 are presented in two ways: (1) the effect of loneliness and (2) controlling for the negative affect (social anxiety and depression) of loneliness in the analyses.

Type of analyses for results

Research on loneliness suggests that loneliness exists on a continuum of severity, with non-loneliness and milder states of loneliness to severe loneliness forming a continuum. However, Cacioppo et al., (2006) argued that severe loneliness is qualitatively different from milder forms of loneliness or non-loneliness. This suggests that attention or behaviour may be different between severe lonely groups and milder lonely or non-lonely groups, with severe lonely people characterized by a specific type/subset of processing or behaviour. In support of this Qualter et al., (2013b) found that lonely children who scored in the top quartile (25%) of the loneliness measure showed different attentional processing biases to social threat information compared to those who were milder or non-lonely. Therefore, the empirical chapters in the thesis assess the linear and curvilinear (quadratic) relations between loneliness and hypervigilance to social threat hypothesis (studies 1, 2, 3, 4 and 5, with the exception of study 6) to investigate if the association is quadratic and discontinuous. Thus, rather than examine prolonged loneliness, the current thesis examines chronic loneliness at any given time.

Effect sizes

An effect size describes the magnitude of an effect or the strength of the relationship between the IV and the DV. Recently, researchers have argued the need to report the effect sizes of research studies alongside the statistically significant values because this informs the reader on whether an effect was found (p value) and the what the size of this effect was (effect size) (Sullivan & Feinn, 2012). Different indices of the effect measures were used for different analyses conducted in this thesis.

In regression analyses, the standardized beta coefficient (β) is used as an indicator of a correlational effect size. The larger the β coefficient indicates that there is a stronger relationship between the predictor and criterion variable (Raju, Fralicx, & Steinhaus, 1986; Grissom & Kim, 2012; Nieminen, Lehtiniemi, Vähäkangas, Huusko, & Rautio, 2013). Therefore, the standardized beta coefficients (β) are reported as the effect size indicators for the regression analyses of studies 1 to 5. In addition, the partial eta squared (ηp^2) values are the most commonly used effect size indicators for the ANOVA analyses (Grissom & Kim, 2012; Vacha-Haase & Thompson, 2004). Therefore, in this thesis the ηp^2 are reported as the effect size for studies 1 to 5.

Effect sizes for the EEG data in study 6 are not reported because the new analytic tool used in that study has not been adapted to give such effect size information .The results were based on 95% and 99% confidence intervals.

Ethical processes

For all the studies described in this thesis, the correct ethical processes were followed and ethical approvals were granted before the studies were conducted. Copies of the ethical approval letters for the studies can be found in appendix A of the thesis. Study 1 was approved by the ethics committee at the University of Central Lancashire as an additional research study to a larger ethically approved study using the same video stimuli in a child sample (Qualter et al., 2013b). Studies 2 to 5 were also approved by the ethics committee at the University of Central Lancashire, whilst study 6 was approved by the ethics committee at the University of Chicago. For study 6, additional training approval was granted by the Collaborative Institutional Training Initiative (CITI). The CITI course was completed online by the lead researchers involved in the study based in the UK (Munirah Bangee and Pamela Qualter) before data collection commenced at the University of Chicago. The online course included modules on responsible conduct of research, data management, research misconduct and collaborative research.

Ethical issues were considered for all the studies included in this thesis and certain measures were put in place to overcome these issues. A brief overview of the main ethical issues is provided here. Confidentiality of the participants was maintained at all times during the studies. No personal data was recorded (except for age and gender) and the data were anonymised (i.e. participants could not be personally identified by the data). Participants were given the right to withdraw from the studies at any time during and until the end of the studies. Feedback on the questionnaire measures (e.g. loneliness scores) were not given to participants individually, but instead feedback on the summary of scores for all participants on all measures was available on request.

Studies 3 to 6 used an online questionnaire to pre-screen participants on loneliness in an attempt to recruit participants scoring high/low on the loneliness scale and to obtain a wide distribution of loneliness scorers. This recruitment approach was approved by the ethics committee at the University of Central Lancashire and University of Chicago and took a two-prong approach. First, a general recruitment advertisement was placed around campus and in the University’s mailing lists that is distributed to all staff and students. The

University's SONA system was also used to recruit students. After 10 participants, the sample was reviewed to assess whether a balanced number of low and high scorers on loneliness had been recruited. If a *balanced sample* was obtained this recruitment approach was continued, reviewing after every 10 new participants. Second, if there were too many individuals scoring high on loneliness OR too few individuals scoring high on loneliness (the latter was anticipated) a screening approach to recruitment was instigated. This involved placing an advert in the mailing lists for participants to complete an online screening questionnaire (loneliness and emotional intelligence measure). The advertisement contained a link to a brief participant information sheet. The participants were given the option to continue and complete the questionnaire. Finally, the required numbers of individuals from the low and high loneliness groups were selected at random and an email was sent out asking them to take part in the main study; no feedback was given to participants with regards to individual scores on the measures assessed. That approach ensured that the required sample was obtained to address the research questions.

Research aims for the current thesis based on the model of loneliness as follows:-

- Directly examine the hypervigilance to social threat hypothesis by using valid methods.
- Bridge the gap in the current knowledge to examine the visual attention processing of lonely adults to social threat using eye-tracker methodology and compare/contrast to findings from eye-tracker research in lonely children.
- Extend the literature on visual attention processing of lonely adults to investigate the processing of emotional information depicted as facial expressions
- Attempt to conceptualise social threats for lonely people in the hypervigilance to social threat hypothesis. Is it a generalised bias to all social threats or is it a specific bias depicted as social rejection/exclusion stimuli? Based on previous research, a specific bias may be conceptualized as a threat to one's social status (i.e. social devaluation, rejection and discrimination), while a general bias may be conceptualized as a threat to all general threats such as negative emotional information.

- Extend the work on hypervigilance to social threats (depicted as social rejection) hypothesis in line with the current findings in the thesis and literature to examine how these stimuli are processed in the brains of lonely adults.

Chapter 3: Study 1 - Loneliness & cognitive processing of real-life footage*

Abstract

Cacioppo and Hawkley (2009) have hypothesised that lonely people are hypervigilant to social threat, with earlier work (Jones & Carver, 1991) linking this bias specifically to threats of social rejection or social exclusion. The current study examined this hypothesis in eighty-five young adults (mean age = 18.22; SD = 0.46; 17-19 years in age) using eye-tracking methodology, which entailed recording their visual attention to social rejecting information. Based on previous eye-tracker literature (Hermans et al., 1999), time-blocks were used to assess visual attention within the first four seconds of the video stimuli. The study found a quadratic relation between the participants' loneliness, as assessed by the revised UCLA loneliness scale, and their visual attention to social threat immediately after presentation (2 seconds). In support of Cacioppo and Hawkley's (2009) hypothesis, it was found that young adults in the upper quartile range of loneliness exhibited visual vigilance of socially threatening stimuli compared to other participants. There was no relation between loneliness and visual attention to socially threatening stimuli across an extended subsequent period of time. Implications for intervention are considered.

Introduction

Cacioppo & Hawkley's model of loneliness (2009) proposes that loneliness is associated with hypervigilance to social threat. This could mean that lonely people in their everyday lives (1) fail to make accurate appraisals of social events, such that they misinterpret social events negatively, but also (2) that they have visual attention biases, such that they are 'on the look out' for negative social events so that they can avoid them and protect themselves against psychological pain. Empirical research, thus far, has focused on the first of these two possibilities, but there is a major gap in our knowledge regarding whether lonely adults show visual attention biases to social threat information. The current study directly assesses whether there are differences between

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* This study is published as Bangee, M., Harris, R. A., Bridges, N., Rotenberg, K. J., & Qualter, P. (2014). Loneliness and attention to social threat in young adults: Findings from an eye tracker study. *Personality and Individual Differences*, *63*, 16-23.

lonely and non-lonely adults in the way they attend to social threatening stimuli using eye-tracker methodology.

Use of eye-tracker technology to measure attention deployment

The use of eye-tracking measures allows an examination of sustained visual processing and is ideally suited for a study of information processing amongst lonely people because the line of visual gaze can be assessed relatively continuously across long periods of time (Hermans et al, 1999). In the eye-tracking literature, there are different patterns of attention processing to threat stimuli: (1) initial vigilance and maintenance relates to the orientation of attention to threat (Armstrong & Olatunji, 2012), (2) disengagement difficulties refers to attention being captured by the threat stimuli (see Buckner, Maner, & Schmidt, 2010), and (3) attentional avoidance refers to orienting attention away from threat (see Lange et al., 2011). The latter attention process is thought to occur on a later timescale during extended viewing as it is under voluntary control (Cisler & Koster, 2010). Based on Cacioppo and Hawkley's (2009) model of loneliness, one would expect to find an attentional bias amongst lonely adults that reflects the initial vigilance and maintenance (i.e. hypervigilance) pattern of attention processing.

The current study

There has been little examination of visual attention and loneliness, specifically in response to social threats that are linked to social rejection or social exclusion. The current study, examines whether lonely young adults displayed attentional biases towards socially threatening stimuli, and if so, which pattern of attentional processing was evident. The study consists of testing the pattern of eye-gaze in lonely and non-lonely young adults when viewing social scenes that include both positive and socially threatening stimuli. This is the first study to assess attention-processing styles in lonely adults using eye-tracking technology to gain a continuous measure of selective attention for socially threatening information.

Method

Participants

The sample included 85 undergraduate students (M = 33; F = 52) studying at a university in the North West of England, UK. The mean age of participants was 18 years and 2 months (SD = 4 months)**.** The age range was between 17 and 19 years.

Measures

Loneliness

Loneliness was measured using the University of California, Los Angeles Loneliness scale (UCLA; Russell, 1996). The scale comprises 20 questions, including 'How often do you feel that you lack companionship?' and 'How often do you feel left out?'. Participants rated how often they felt the way described in each statement on a 4-point scale (1 = never, 2 = rarely, 3 = sometimes, 4 = often). Scores for each statement were summed to give a total loneliness score. The possible range of scores for the full measure was 20-80, with higher scores indicating higher levels of loneliness. In this sample, the loneliness scores ranged from 24-74, with no difference between males and female participants ($t = .404$, $p = .687$). The scale exhibited excellent internal consistency in the current study, $\alpha = .98$.

Video stimuli

Video footage included social scenes of adolescents during lunch or free periods, depicting both positive and negative social interactions. The footage was taken from colleges and schools in the North of England. The video stimuli consisted of eight clips, with each clip lasting 20 seconds; there was a 3 second interval between each clip. The session started with a centrally fixated cross, followed by the viewing of the eight clips. The order of clips was counterbalanced for each participant to reduce order bias. Each clip included some form of socially threatening behaviour (lone individual ignored by a group of peers, discordant body posture [turning of back on another member of the group]) and positive behaviour (smiling, encouragement in the form of nods, leaning into a conversation) that were present on screen at the same time. The clips featured at least two small groups of peers; at least one group showed positive behaviour, whilst the other group included negative behaviour. The current study used the same video stimuli as that used in an eye-tracker study examining loneliness in children (Qualter et al, 2013b).

The threatening clips used in the experiment were classified as 'unpleasant' and 'a good example of rejecting behaviour' on a 5-point rating scale by two samples of participants (119 undergraduate students [age range: 18-56 years; F = 75; M = 44; 129 children [age range: aged 8-14 years; F = 86; M = 43]).

Eye-tracking system

Eye tracking equipment was used to measure eye movements (visual fixation and scanning) during the course of the eight clips. The eye-tracking device used was an iVIEW X HED model with a dual ocular recording at 200 Hz. The recording was done in stereo bi-ocular recording. Eye movements of each participant were followed precisely and areas of interest were identified and monitored. These areas of interest were (1) threatening stimuli: Individual in the socially rejecting group/dyad or person being rejected/experiencing negativity from others, and (2) non-threatening stimuli: Individual(s) not in the rejecting group.

Attention was operationalized in terms of eye fixations. An eye fixation was recorded whenever the participant stopped or had a saccade (rapid eye-movement) in one of the two areas of interest. To investigate patterns of attention over time, time-blocks were used to examine the proportion of time fixating on the social threat stimuli relative to the total captured fixation time for each time block. The use of time-blocks is recommended in the literature looking at attention in eye-tracking studies (Hermans et al., 1999). To ensure the capture of initial vigilance, then any avoidant patterns of visual attention that may be evident amongst the lonely sample, the first 4 seconds of viewing time was examined independently. The first 4 seconds were important because the details of the rejection situation are apparent then. We also examined whether the pattern of attention changed over the full 20 seconds of viewing time. These examinations allowed a direct comparison with the findings from the eye-tracking study with lonely children. For the purpose of the eye-tracker study, hypervigilance is defined as an attentional bias or selective attention to threat stimuli. For lonely people, hypervigilance to social threats may be characterized as an attentional bias, which puts the brain on high alert for those threats.

Procedure

After informed consent was gained, participants completed the UCLA loneliness measure in a laboratory room at the University. Participants were then positioned to sit at a pre-determined distance of 60 cm away from the 15-inch laptop display with a 1024 x 768 pixels resolution. The eye tracker was calibrated for each participant and they were asked to view the eight clips as if they were watching television. Eye movements and areas of interest were recorded in the eye-tracker

Data analyses plan

The analyses for this study include linear and quadratic (curvilinear) analyses and those are reported in the results section below. For the examination of significant linear and/or quadratic effects; the loneliness group is based on the extreme top end of the loneliness scores. In this study, a loneliness score of 65 or above was used as the lonely group. This was because the extreme scorers are likely to show differences in processing compared to other scorers on loneliness. The cut-off point of 65 was used to define extreme loneliness in the study because it reflects the upper quartile of scores for the UCLA loneliness scale.

Results

Attention deployment of social threat stimuli

Regression analyses were used to examine the linear and quadratic associations between loneliness and attention to social threat stimuli. Loneliness was the predictor variable in these analyses; the percentage of fixation time on the threatening stimuli across 8 time intervals ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, and 4000ms were the criterion variables. Analyses showed significant linear and quadratic relations for loneliness across the first 3 time intervals (0-1500 ms) (linear: $\beta s \geq .47$, $ps < .002$; quadratic: $\beta s \geq 2.20$ $ps < .004$). Figures 3.1 - 3.3 show these quadratic relations: as expected, those participants very high on loneliness showed a greater frequency to view the socially rejecting stimuli than those in the remainder of the sample. For the remainder of the time intervals, no linear or quadratic relations were found (βs $\leq$ .12, *ps* >.05). Where curvilinear effects were found, these are reported with the linear effect controlled. The same patterns were found across gender, such that there were significant linear and quadratic relations across the first three time points only (linear: M = βs $\geq$ .52, *ps* < .01, F = βs $\geq$ .395, *ps* < .003; quadratic: M = quadratic: βs $\geq$ 2.18 *ps* < .05, F = βs $\geq$ 2.98 *ps* < .004).

To further examine the quadratic effects and establish whether attention to the social threat stimuli was biased in lonely participants who were in the upper quadrant of loneliness scores, a 2 (group: lonely versus non-lonely) x 8 (time interval, ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, and 4000ms) mixed design ANOVA was conducted. Membership of the lonely group was determined by having a score in the upper quadrant of the loneliness scores (N = 10; F = 6); all other participants were classified as non-lonely (N = 75; F = 46). Scores for people in the upper quadrant represent those with severe levels of loneliness, with means for males (70, SD = 2.16) and females (71.83, SD = 1.60) being within the top quartile of the UCLA scoring range (above 65). There were no gender differences on loneliness so the effects reported are not driven by gender.

The ANOVA results showed a main effect of time (F = 44.79, p < .001, ηp^2 = .80), and a main effect of lonely group (F = 4.78, p = .023, ηp^2 = .05). Further, there was a time x lonely group interaction (F = 9.81, p < .001, ηp^2 = .47). The time course of attention to the threatening stimuli was different for lonely and non-lonely participants, with means showing lonely participants were fixed on the threatening stimuli within the first 2 seconds of viewing time (see Figure 3.4). Post-hoc testing using follow-up one-way ANOVAs revealed that lonely and non-lonely participants were different in the amount of viewing time they spent looking at the threatening stimuli over the first three time intervals only (*Fs* [dfs = 1, 84] $\geq$ 11.85, *ps* $\leq$ .001, ηp^2 > .12). However, after this, the groups no longer differed, with lonely participants spending a similar amount of time as non-lonely participants on the socially threatening stimuli (*Fs* [dfs = 1, 84] $\leq$ .60, *ps* $\geq$ .441, ηp^2 < .007).

To examine the attention patterns of lonely and non-lonely participants over the full viewing time, each 20-second clip was divided into four 5-second segments. Differences between the lonely and non-lonely groups were examined on the percentage of fixation time on the threatening stimuli during the four 5-second segments that made up the full viewing time. ANOVAs revealed differences only during the first 5 seconds consistent with our first set of analyses (F [dfs 1,84] = 3.23, $p < .046$, $\eta p^2 = .05$), but not for the remainder of the viewing time (Fs [dfs 1, 84] < .87, $ps < .201$, $\eta p^2 > .02$). Thus, lonely participants were different in their initial viewing behaviour, but after 2 seconds showed similar avoidance of the socially threatening stimuli as did non-lonely participants. Figure 3.5 shows the means for lonely and non-lonely adults across the four 5-second segments of viewing time. No significant differences were found for loneliness and attention to positive stimuli in the social scene using the same regression analyses as noted above.

First fixation

Chi-square analyses showed that lonely participants in the upper quartile of the loneliness scores were more likely than chance to have their first fixation on the socially threatening stimuli while non-lonely participants were more likely to fixate first on the positive stimuli in the social scene (χ^2 [df 1] = 30.34, $p < .001$).

Figure 3.1: Linear and quadratic relations between loneliness and the viewing of socially rejecting stimuli at 0-500ms.

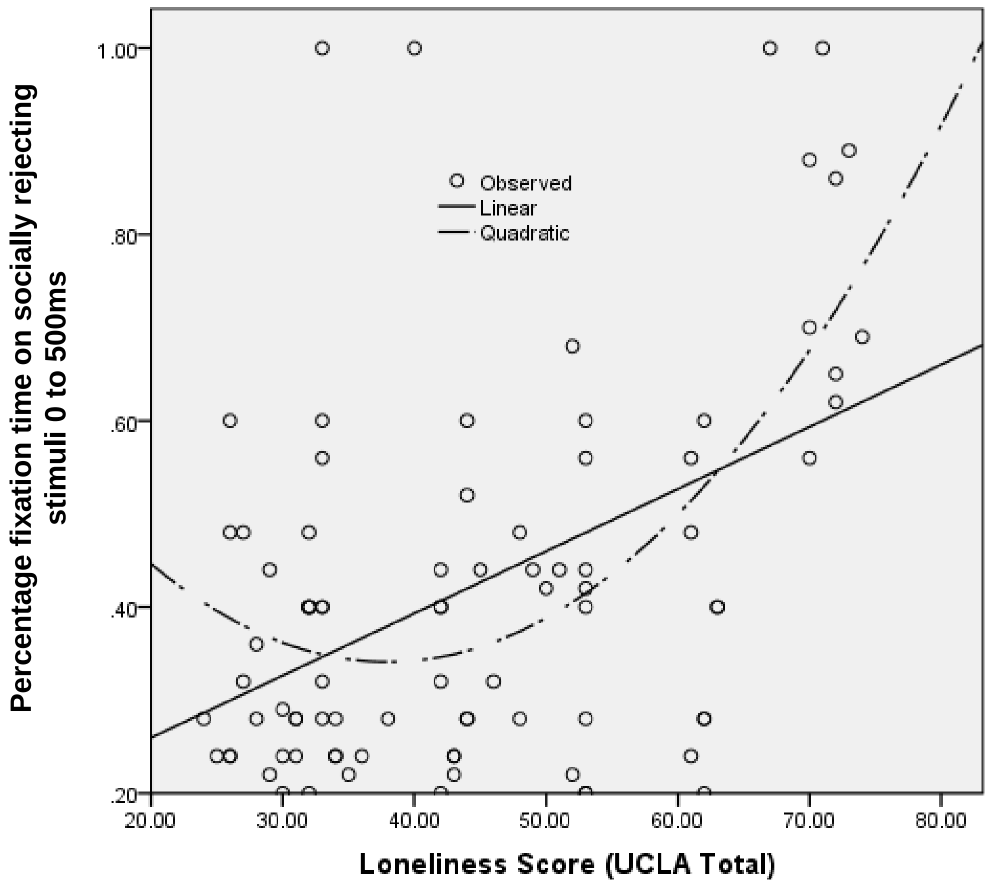


Figure 3.2: Linear and quadratic relations between loneliness and the viewing of socially rejecting stimuli at 501-1000ms.

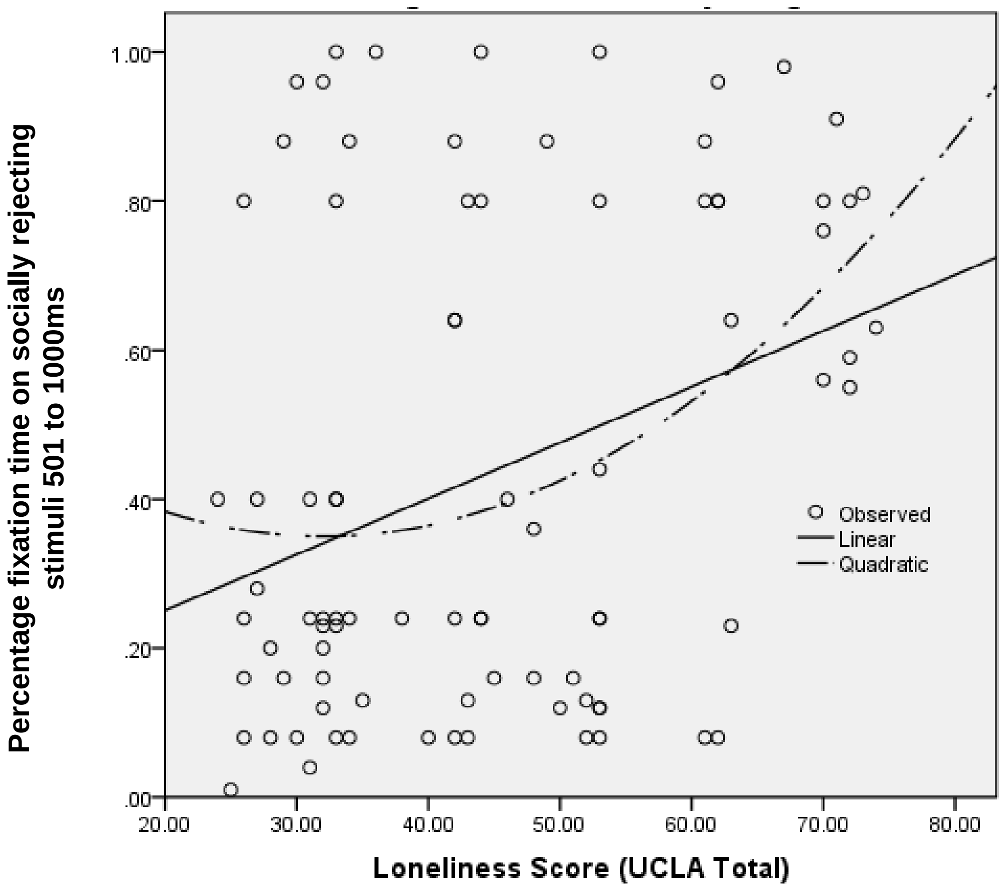


Figure 3.3: Linear and quadratic relations between loneliness and the viewing of socially rejecting stimuli at 1001-1500ms.

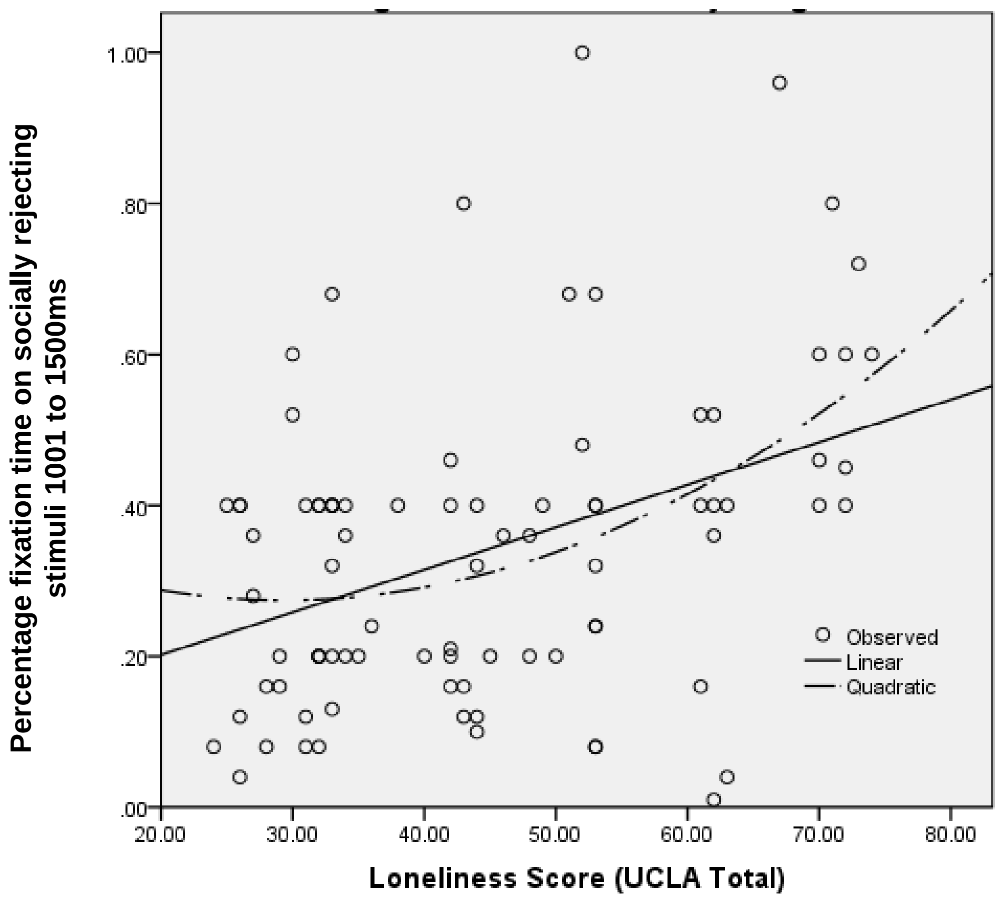
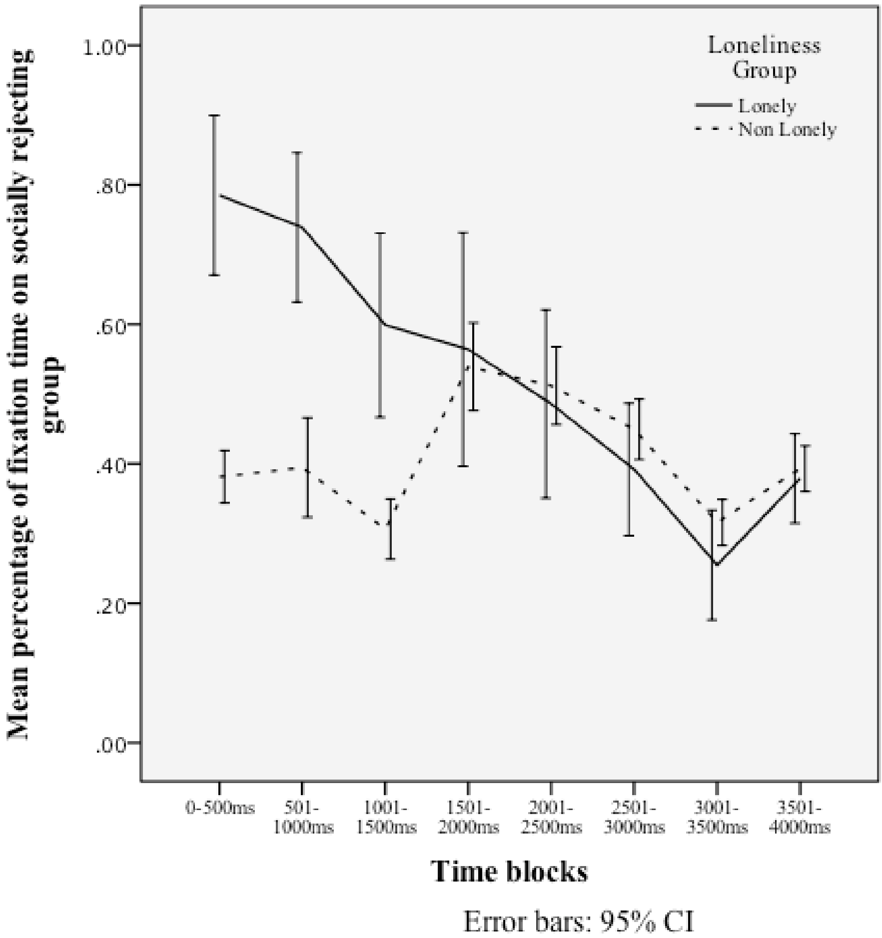
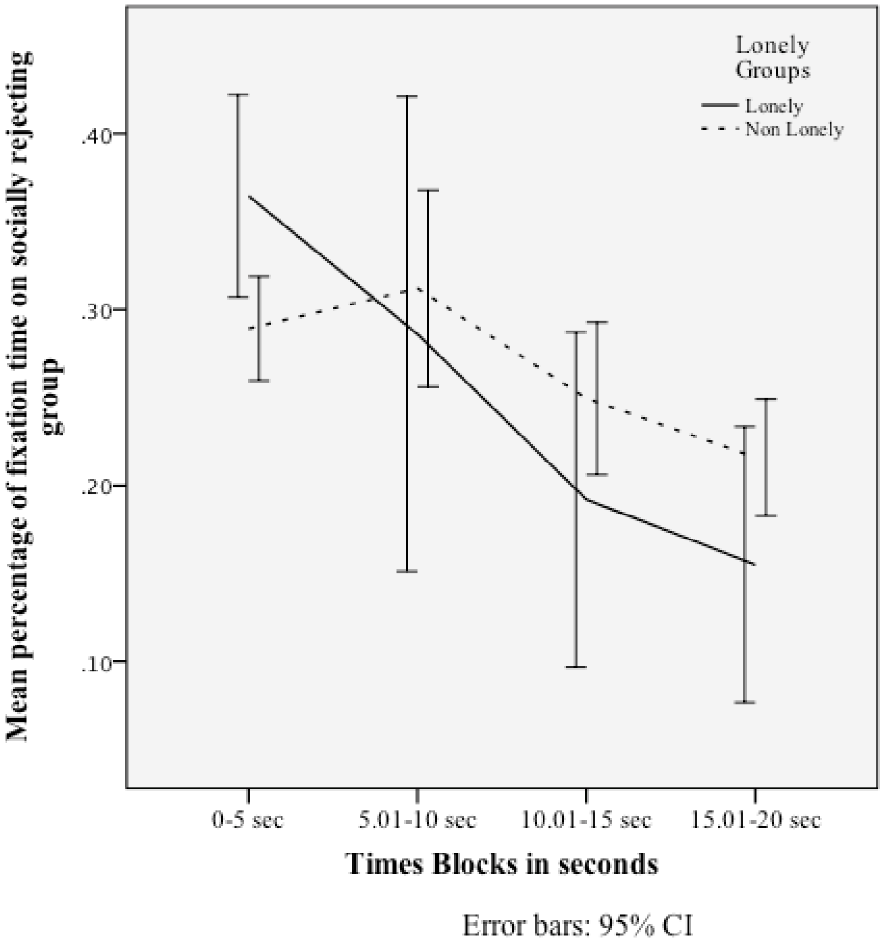


Figure 3.4: Percent of total fixation time viewing the socially threatening stimuli during the first 4 seconds of viewing time



Notes: Lonely adults were those that scored in the upper quadrant of the UCLA. Post-hoc tests showed that the lonely groups differed for the first 3 time blocks (ending at 1500ms). However, after that, lonely young adults avoided the social threat stimuli in a similar way to non-lonely peers.

Figure 3.5: Percent of total fixation time viewing the socially threatening stimuli across 5-second segments of the full 20 seconds of viewing time



Notes: Adults in the lonely groups were those that scored in the upper quadrant of the UCLA. Post-hoc tests showed that lonely young adults were significantly different to non-lonely young adults in their viewing of the social threat stimuli for the first 5 seconds of viewing time only; lonely and non-lonely participants were no different during the other three time blocks (5.01-20 seconds).

Discussion

The current study is the first study to examine hypervigilance to social threat stimuli in lonely adults using eye tracker methodology; it used dynamic social stimuli to determine how hypervigilance to social threat might work in real life for lonely people. The findings showed that very lonely young adults, those in the upper quadrant of loneliness scores, were more likely to fixate first on the socially threatening stimuli than were their non-lonely peers. They also appeared to fix their attention on the threat-related stimuli for the first 2 seconds of viewing time, but then showed the same avoidant viewing style as the non-lonely participants. Thus, in line with previous eye-tracker studies on attention processing biases (i.e., Lange et al., 2011), initial vigilance towards threat stimuli was found and evidence of subsequent attentional avoidance of those same stimuli.

These findings are consistent with the model of loneliness that posits lonely people display biased attention for social threat, specifically to rejection and exclusion stimuli (Cacioppo & Hawkley, 2009). This study also extends previous work by (1) examining visual attention biases in a sample of lonely young adults, and (2) showing that lonely young adults have a pattern of attention processing consistent with initial hypervigilance of social threat and later avoidance of these stimuli. Taken together with previous studies assessing social information processing biases of lonely people, there appears to be a robust association between loneliness and cognitive biases for social threat.

Why do lonely young adults show a different pattern of attention to social threat compared to lonely children?

In the current study, the same stimuli were used to that in the eye-tracker study looking at loneliness in children, but the pattern of visual attention processing found for lonely young adults was different to that reported for lonely children (Qualter et al, 2013b). Lonely young adults showed an initial vigilance to the social threat stimuli, but this pattern was not previously found for lonely children who had been exposed to the same stimuli. These initial biases in eye-gaze towards social threat may be more pronounced in lonely young adults because they have had longer exposure to their negative expectations. Cacioppo and Hawkley (2009) refer to this as the regulatory loop, where cognitions increase the likelihood that lonely individuals will engage in negative social behaviour (i.e., passivity) that elicit negative responses from others, increasing feelings of loneliness and reinforcing cognitive biases, even if feelings of loneliness are transient.

These findings also provide evidence that lonely young adults show attentional avoidance of social threatening stimuli, while lonely children showed difficulty disengaging from these stimuli. Changes in cognitive ability, particularly the ability to relocate attention, are likely to be implicated in these changes in information processing and may play a part in maintaining loneliness. For example, the ability to control attention remains immature until cognitive developments in adolescence (Anderson, Anderson, Northam, Jacobs & Cutroppa, 2001; Puliafico & Kendall, 2006), which could explain why lonely children show a pattern of poor disengagement while lonely young adults show a pattern of visual attention characterised by initial vigilance and then avoidance. Future work should assess executive functioning abilities, such as processing speed and voluntary response suppression, to determine how these abilities impact on the way lonely adults and children attend to threat-related information and disengage from it.

Implications for interventions

The current findings suggest lonely young adults show hypervigilance and subsequent avoidance of social threat. They support the idea that interventions for lonely people should focus on addressing cognitive biases (Masi, Chen, Hawkley & Cacioppo, 2011). Specifically, attentional biases should be targeted for lonely adults such as incorporating the skills to cope with social threat situations. The findings also indicate that cognitive-behavioural strategies would best support those that are very high on loneliness and this group should be the primary focus for any interventions.

Strengths, Limitations, and Directions for Future Study

A major strength of the current study is the use of eye-tracking technology. This enabled the assessment of both early (vigilance) and later (avoidance) processing of attention continuously thus giving the ability to examine fully whether lonely young adults were hypervigilant to social threat. Another strength is the use of video footage from real social situations, which is a more naturalistic measure of social threat than photographic faces that typically serve as a proxy measure for social stimuli (Garner, Mogg, & Bradley, 2006). Future work should examine these attention-processing biases in actual social situations. Such investigations would explore whether there are different patterns of attentional deployment for lonely versus non-lonely people when engaged in actual socially threatening situations. Future work should also investigate whether similar patterns of attention processing are evident when stimuli depicting mild or moderate social threat are used.

There are some limitations to the study that indicate directions for future work. Social anxiety and depression were not measured in the current study. Although both these constructs are differently associated with loneliness, they could account for the relationship between loneliness and hypervigilance to social threats using eye-tracker systems (see chapter 4). Thus, future work should examine the effects of loneliness, social anxiety and depression to determine the significance of loneliness on attention deployment.

The use of video footage of real social situations was noted as a strength of the study, however emotional information was not coded from the video footage. Future work should examine loneliness and hypervigilance to social threats depicted as emotional information.

Conclusion

These findings provide some support for Cacioppo and Hawkley's (2009) model of loneliness that proposes loneliness is associated with hypervigilance to social threat stimuli. The findings show that lonely young adults attend to information that is socially threatening more than non-lonely peers. Also, the findings suggest that there is a distinct pattern of attention deployment that characterises lonely young adults who score in the upper quadrant of the loneliness scores. Lonely young adults are (1) more likely to view social threat stimuli as their first fixation than non-lonely peers, (2) more likely to fix their attention on threat stimuli initially, and (3) quickly avoid (after 2 seconds) the social threat in line with non-lonely adults. These patterns of visual processing are interpreted as evidence that loneliness is associated with hypervigilance to social threat. It is proposed that these patterns of attention are likely to influence behaviour, including withdrawal and aggression in social situations, and distrust of others, which contribute to the maintenance of loneliness.

Closer look at the limitations of the study

As mentioned briefly above in the discussion, the current study has limitations that suggest direction for future work in the research area. The two major limitations of the study are as follows:

(1) Social anxiety and depression were not statistically controlled in the analyses. This is important because these two constructs overlap with

loneliness and are known to overlap with cognitive/attentional biases using eye-tracker methodology. Detailed overviews of these ideas are discussed in the next section (chapter 4). Therefore, in the next set of studies in chapter 4, the results are reported with the effect of loneliness, and controlling for the negative affect of loneliness with the constructs social anxiety and depression in the analyses.

(2) Only the social scenes from the video footage were coded. The above study did not examine attention to emotional information (i.e. facial expressions) within the social scene. This is important because lonely people may be hypervigilant to social threats depicted as negative/threatening facial expressions and this may put them on high alert or they may misinterpret these social cues in the social environment. Therefore, the next set of studies use static/stationary images of facial expressions and images from the IAPS database, instead of using video footage to examine these ideas.

The next set of four studies included in chapter 4 address the two outlined gaps in the research and extends the work previously conducted in this area relating to the cognitive processing of lonely adults. The next set of studies also addresses the limitation of age range; this was widened to participants between 18 and 30 years.

Chapter 4: Cognitive processing of lonely adults to static images

Abstract

Prior research has shown that loneliness is associated with hypervigilance to social threats, with eye-tracker research showing lonely people display a specific attentional bias when viewing social rejection and social exclusion video footage (Study 1; Qualter et al., 2013b). The current set of four studies use a cognitive paradigm and eye-tracker methodology to examine whether this attentional bias is generalised to threat stimuli depicted as emotional facial expressions or whether it could be explained by a specific bias to social rejection. Participants completed a cognitive eye-gaze perception task in study 2. A different sample of participants were asked to view slides displaying 4 faces each with different emotions (anger, afraid, happy and neutral) in study 3, slides displaying 16 faces with varying ratios of happiness and anger in study 4, and slides displaying 4 visual scenes (socially threatening, physically threatening, socially positive, neutral) in study 5 while eye movements were recorded in real time with an eye-tracker. Results demonstrated an association between loneliness and viewing patterns of angry facial expressions, and an association between loneliness and a hypervigilant viewing pattern for social rejecting stimuli. The findings indicate that lonely adults may have a generalised hypervigilance to social threat, but they show a specific attentional bias to rejection information in a social context.

Introduction

Cacioppo and Hawkley's (2009) model proposes that loneliness is related to hypervigilance to social threats that alter the processing of social information. Thereby, lonely people view and are more attentive to social threats in the social world which are likely to modify their behaviour (e.g. social withdrawal) and undermine the opportunity to develop and maintain positive social relationships. Findings from study 1 revealed that lonely young adults show an attentional pattern of hypervigilance-avoidance to social rejection cues when viewing real-life video footage of social scenes. Specifically, lonely young adults were more likely to fixate first and initially spend a greater amount of viewing time on the social threat stimuli compared to non-lonely adults, but then lonely young adults were found to avoid the stimuli in line with non-lonely adults.

However, there are limitations of that study which the next set of studies aims to address and extend the knowledge in the loneliness field. The next set of studies examines the hypervigilance to social threat hypothesis in loneliness whilst statistically controlling for social anxiety and depression in the analyses because of their known overlap with loneliness and cognitive biases (see below). In addition, the next set of studies investigates this hypervigilance to social threat hypothesis using static images of emotional facial expressions and images of visual scenes from the IAPS database, instead of using video footage that did not examine emotions of facial expressions or static scenes.

Interplay of related constructs with loneliness

The present empirical chapter focusses on the related constructs (depression and social anxiety) for two important reasons: (1) the known overlap with the construct of loneliness, and (2) the overlap with cognitive biases. The two reasons are discussed here.

(1) Overlap with the construct of loneliness

Depression

Loneliness is strongly correlated with depression (r = .40 to .60), with many researchers viewing loneliness as a symptom of depression, as evidenced by the inclusion of loneliness items (i.e. I felt lonely) on questionnaire measures for depression (Radloff, 1977). However, theoretical and empirical evidence has suggested that loneliness and depression are distinct constructs. A previous study found that loneliness and depression were correlated, but neither construct was associated with each other over time (Weeks, Michela, Peplau & Bragg, 1980). Recently, longitudinal studies have consistently found that loneliness predicts increases in depressive symptoms (Cacioppo et al, 2006; Cacioppo, Hawkley & Thisted, 2010; Qualter et al, 2010, 2013; Vanhalst, Luyckx, Teppers & Goossens, 2012). Furthermore, loneliness and depression had different associations with personality traits (Vanhalst, Klimstra, Luyckx, Scholte, Engels & Goossens, 2012) and suicidal thoughts (Lasgaard, Goossens & Elklit, 2011). The evidence suggests that loneliness is related to depression, but the two constructs are different. Theoretical evidence has been shown to support this claim: loneliness involves the distress from an individuals' social life only, whereas depression involves the distress on a global level from multiple facets of life (cf. Heinrich & Gullone, 2006).

Social anxiety

Anxiety, specifically social anxiety, is another construct that has been linked to loneliness. Social anxiety is defined as the inability to interact in social situations and a fear of negative evaluation by others (Creed & Funder, 1998). This definition indicates a theoretical overlap between loneliness and social anxiety. Social anxiety is associated with loneliness in adolescence samples with medium effect sizes reported in a meta-analysis of 12 studies (Mahon, Yarcheski, Yarcheski, Cannella & Hanks, 2006) and adolescents with social phobia report significantly higher levels of loneliness (Biedel, Turner, Young, Ammerman, Sallee & Crosby, 2007). Further, London et al., (2007) argued that loneliness and social anxiety are distinctive constructs; in their study, loneliness and social anxiety were found to be differentially associated with the construct sensitivity to rejection longitudinally. However, research in this area suggests that loneliness and social anxiety are distinctive constructs. In a review of the literature, Jones, Rose & Russell (1990) report that proportion of variance shared by loneliness and social anxiety measures is 16 to 25% implying a large amount of variance is unexplained by the two measures.

Summary

Both theoretical and empirical evidence support the fact that loneliness is correlated and shares common features with social anxiety and depression, but they are clearly distinguishable constructs (Jones et al, 1990; Weeks et al, 1980). Researchers have emphasised the need to statistically control for these two constructs when examining loneliness. However, an alternative view that some researchers hold in the field highlights the question of validity of the loneliness construct, such that statistically controlling for social anxiety and depression may actually remove the negative affect that is vital for the central construct of loneliness and the variance left is not loneliness. This is a re-emerging theme in the literature which needs to be addressed.

(2) Overlap with cognitive biases

The literature on loneliness suggests that lonely people attend more to negative social information, remember more negative social events, and interpret the social world more negatively compared to non-lonely people (refer to chapter 1 for detailed overview). Therefore, loneliness is associated with cognitive biases. Likewise, the literature on depression and social anxiety has examined the relationship between cognitive biases in individuals with social anxiety and depression symptomology. This section provides an overview of the extent to which depression and social anxiety are related to cognitive biases. Thus includes findings for attention/memory biases, perceptual biases and, when examining the hypervigilance to social threat hypothesis using, eye-tracker technology.

Depression and cognitive biases

(a) Evidence for attention/memory biases

A number of empirical findings suggest that depression is not characterised by automatic attentional biases, but with later stages of processing, thus, they show a selective bias to negative information (Gotlib & Joorman, 2010). A recent meta-analysis including empirical studies utilising the emotional stroop task and dot probe task indicates that individuals with depression preferentially attend to negative stimuli compared to non-depressed individuals (Peckham, McHugh & Otto, 2010). In addition, depression is related to the recall of negative information compared to positive information (Matthews & MacLeod, 2005), suggesting depressed individuals have a characteristic response bias for negative events. Specifically, a meta-analysis review found that individuals with depression preferentially recalled negative information and non-depressed individuals preferentially recalled positive information (Gaddy & Ingram, 2014).

(b) Evidence for perceptual biases

The research on whether depression is characterised by negative perceptual interpretations is not consistent. A number of empirical studies have found that individuals with depression do not interpret social situations more negatively compared to non-depressed individuals (Gotlib & Joorman, 2010) or show interpretative biases to ambiguous sentences (Bisson & Sears, 2007). However, a number of studies report that individuals with depression interpret emotional ambiguous information in a more negative fashion (Wisco & Nolan-Hoeksema, 2010).

(c) Evidence for hypervigilance to social threat hypothesis using eye-tracker technology

Limited, but consistent, research is available for the course of attention deployment in depression. Empirical evidence using eye-tracker methodology has failed to find initial attentional processing biases (Mogg, Miller & Bradley, 2000). Instead the depression literature has implied that an attentional bias occurs over a longer exposure time during later processing of stimuli. Attention biases in depression and dysphoric adult samples are characterized by impairment in disengaging from negative emotional information (Caseras, Garner, Bradley & Mogg, 2007; Kellough, Beevers, Ellis & Wells, 2008; Sears, Thomas, LeHaquet & Johnson, 2010). This suggests that a disengagement difficulty to negative information is likely to be a strategic process followed by an inability to shift attention from negative cues. The same attention pattern is found amongst lonely children (Qualter et al, 2013b: study 3) suggesting that attention biases are involved in the maintenance of loneliness. But this was not evident for lonely young adults in study 1 of the current thesis.

Social anxiety and cognitive biases

(a) Evidence for attention/memory biases

A number of empirical studies have found that individuals with social anxiety show heightened attention to negative information. Much research in this area has focussed on facial expressions and these studies suggest that socially anxious individuals show an automatic attentional bias (i.e. hypervigilance) towards negative emotions (e.g. anger) (Schulz, Mothes-Lasch & Strobe, 2013). Social anxiety is also characterised by memory biases. Specifically, individuals who are socially anxious are more likely to remember negative information and social events compared to non-socially anxious individuals (Ferreri, Lapp & Peretti, 2011; Morgan, 2010).

(b) Evidence for perceptual biases

Consistent research evidence shows that socially anxious individuals are characterised by negative interpretational biases: they interpret and evaluate social situations more negatively (Ferreri, Lapp & Peretti, 2011; Laposa, Cassin & Rector, 2010). Specifically, an earlier review of the literature drawing on research from a number of different approaches such as questionnaires, self-ratings and experimental tasks (Heinrichs & Hofmann, 2001) indicated that individuals with social anxiety show an interpretational bias towards socially threatening information.

(c) Evidence for hypervigilance to social threat hypothesis using eye-tracker technology

More, but less consistent, eye-tracker evidence has been found for the course of attention deployment in socially anxious adults. The social anxiety literature proposes two distinct patterns for attention processing to social threat stimuli using eye-tracker technology. Firstly, the vigilance-avoidance hypothesis suggests that socially anxious adults initially direct their attention towards the threat stimuli followed by attentional avoidance of the same stimuli (Mogg, Bradley, de Bono & Painter, 1997; Garner et al, 2006). Secondly, socially anxious adults are thought to have disengagement difficulties from threat cues, thus, they are unable to disengage their attention efficiently which is implicated in the maintenance of this disorder (Fox et al, 2002; Schofield, Johnson, Inhoff & Coles, 2012). Consistent evidence from eye-tracker studies and other cognitive paradigms provide support for both of these theories. But there is no conclusive evidence on the directionality of this attentional bias.

Use of static images in eye-tracker research

Most of the eye-tracker research has used static images from a number of databases (International Affective Picture System; IAPS, Karolinska Directed Emotional Faces; KDEF, NimStim facial stimuli set), which has been previously validated. Static images are useful because they provide consistent evidence of how individuals process social information and cues in the environment. Even though the use of static images have been criticised (e.g. proxy measure; Bogels & Mansell, 2004), they have been equivocally and consistently used in research. Static images were used to allow the examination of the effects of loneliness controlling for depression and social anxiety that are known to affect the responses in these experiments.

Current set of studies

The four studies in this chapter aim to systematically examine the hypervigilance to social threat hypothesis and provide support for this. Studies 2, 3, and 4 focus on how lonely adults process different emotions from facial expressions; study 5 investigates the processing of social threats linked to social rejection and social exclusion in lonely adults based on the findings from study 1.

The current sets of studies in this empirical chapter are presented in two ways: (1) the effect of loneliness and (2) the effect of loneliness with depression and social anxiety statistically controlled for in the analyses.

Study 2 - Eye-gaze and emotion perception in lonely adults

Specific introduction

The human face holds relevant information that enables humans to interact within the social world. In particular, eyes are of high biological significance (Lobmaier, Tiddeman & Perret, 2008); understanding where a person is looking and attending is crucial in social interactions. However, eye-gaze interpretation is surrounded by ambiguity. For example, directed gaze can be seen as a sign of threat or friendliness (Macrae, Hood, Milne, Rowe, & Mason, 2002). Eye-gaze perception is influenced by the emotional expression on the face; it has been suggested that angry and happy emotions coupled with directed gaze are associated with labelling emotions faster as evidenced by quicker reaction times to these stimuli (Adams & Kleck, 2003).

Additionally, using eye-gaze and emotion processing paradigms, socially anxious individuals were faster at avoiding the angry faces of the directed gaze, and happy faces irrespective of gaze directions gaze (Heuer et al, 2007; Roelofs et al, 2010). The latter finding suggests that socially anxious individuals may show a different response to how they avoid happy and angry faces. In contrast, individuals with depression did not avoid the angry or happy faces irrespective of directed or averted gaze (Radke, Guths, Andre, Muller & Bruijn, 2014). These results imply that socially anxious individuals are more susceptible to eye-gaze and emotion perception of others. Moreover, loneliness has been shown to be associated with a difficulty in discriminating the eye-gaze of others using a gaze perceptual task, in which participants were asked to indicate the direction of where the face was looking (centrally, left, right) (Kunai et al, 2012). Based on the empirical evidence, it can be assumed that lonely adults may show avoidance of the directed eye-gaze with a more prominent effect for the angry faces. However, based on Cacioppo and Hawkley's (2009) theoretical model, lonely adults may show hypervigilance to the angry directed gaze faces.

Aim of Study 2

Study 2 aims to investigate whether lonely adults are hypervigilant to basic social cues such as eye-gaze and emotional expressions at a subjective level. The study uses a more direct measure of social threat perception (i.e. is this face looking at you?) compared to the task used by Kunai et al (2012), which asked participants to respond to the direction (i.e. central, left, right) the face presented was looking, and that of the stimuli used in study 1 (chapter 3). Study 2 examines this hypothesis with loneliness, and controlling for social anxiety and depression.

Method

Participants

The sample included 40 participants (M = 12; F = 28) including students and staff from a University in North West England, UK. The mean age of participants was 21 years and 6 months (SD = 3 months). The age range was between 18 and 30 years. Two participants were removed from the analyses due to technical errors in the task program. Previous literature suggests that age is a factor which affects cognitive ability in cognitive tasks (Verhaeghen & Salthouse, 1997), so the age range in this study was limited to 18 to 30 years. Out of 56 participants that completed the study, 16 participants were removed from further analyses because they were above the restricted age range.

Measures

Loneliness: Level of loneliness was measured using the University of California, Los Angeles loneliness scale (UCLA; Russell, 1996). This comprises 20 questionnaire items such as ‘How often do you feel left out?’, ‘How often do you feel you are no longer close to anyone?’ and ‘How often do you feel that you lack companionship?’ Participants were required to indicate how often they felt the way described in each statement on a 4-point scale (1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often). The scores for the full scale ranged from 20 to 80. In the current sample, the loneliness scores ranged from 24-70. Mean scores were used in the analyses, with higher scores indicating higher levels of loneliness. The scale exhibited excellent internal consistency $\alpha = .94$.

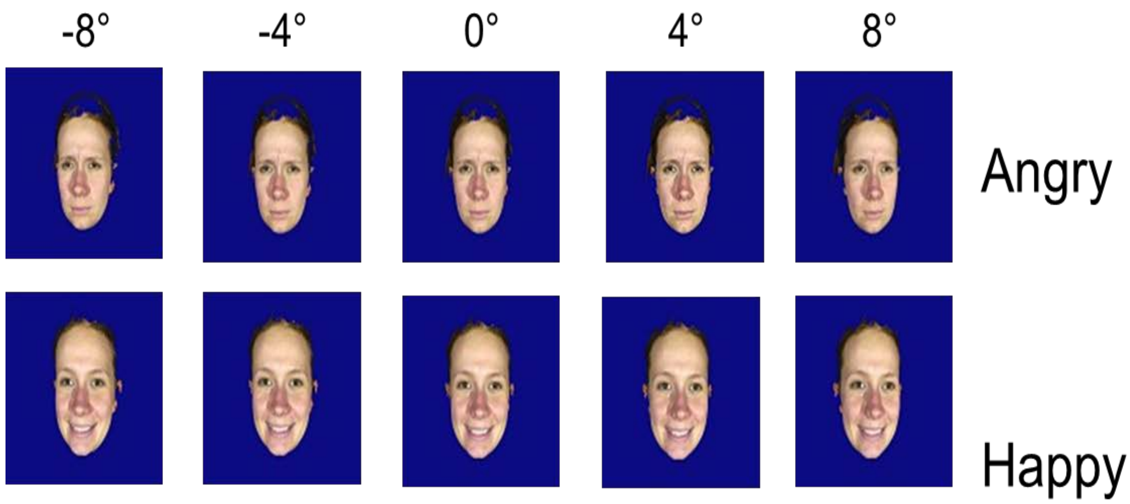
Social anxiety: The Brief Fear of Negative Evaluation Scale (BFNE; Leary, 1983a) and Interaction Anxiousness Scale (IAS; Leary, 1983b; Leary & Knowalski, 1993) assessed the levels of social anxiety. The BFNE includes 12 questions and the IAS comprises 15 questions; participants were asked to rate each statement on how characteristic it is of them using a 5 point scale (1 = not at all to 5 = extremely) for both scales. Higher scores indicated higher levels of social anxiety. Both the BFNE and IAS scales exhibited good internal consistency at $\alpha = .90$ and $\alpha = .91$ respectively. In the analyses, mean scores for the two scales were computed independently.

Depression: The Center for Epidemiologic Studies Depression Scale (CES-D; Rudloff, 1977) was used to assess depressive symptomology. The scale includes 20 questions requiring participants to indicate how often they felt the way described in the past week from four possible options (Rarely or none of the time; some or a little of the time; occasionally or a moderate amount of time; most or all of a time). In the current study the item ‘I felt lonely’ was removed from the total score. Scores were summed and higher scores indicated higher levels of depressive symptoms. The scale exhibited good internal consistency $\alpha = .86$.

Task Stimuli

An adapted version of the eye-gaze perceptual task (previously used and validated by Lobmaier et al, 2008 and Rimmele & Lobmaier, 2012) was used in the current study. Faces of 12 actors (6 males and 6 females) were captured expressing a happy and angry emotion while they fixated their gaze on a pre-determined target 80 cm away using virtual cameras. The 3D models were rotated to give nine different viewing angles 2°, 4°, 6°, 8° to the right and left, and 0°). These were converted into jpeg formats. Each face was presented on a blue background and presented in the centre of the screen (see Figure 4.1 for an example of the faces used in the study).

Figure 4.1: Example face stimuli used in study 2. Top: angry faces presented at five viewing angle (0°, 4° [right, left], 8° [right, left]). Bottom: happy faces presented at five viewing angle (0°, 4° [right, left], 8° [right, left]) in the gaze and emotion perception task.



Task and Procedure

After informed consent was gained, participants completed the set of questionnaire measures described above in a laboratory room at the University. Participants were then asked to sit in front of a computer screen at a comfortable distance and decide whether each face presented on screen was looking straight at them by pressing “K” on the keyboard or not by pressing “D” as quickly as possible. Verbal and on-screen instructions were given and participants initiated the task by pressing the space bar. The task included 9 practice trials and a total of 216 trials in the main task. Each stimulus was presented for 900 milliseconds and presented once in a random order for each participant. Feedback was not given to the participants and the next trial was initiated by a key response making it a forced choice response task.

Data preparation

The mean proportion of "looking at me" answers reported by the participants was computed for each viewing angle and each emotion and for each participant separately. The responses were pooled for the left gaze angles and the corresponding right gaze angles to give five different gaze angles (0°, 2°, 4°, 6° and 8°) for the analyses because differences between the right and left gaze angles were not expected. The overall reaction time (milliseconds) across all gaze angles for each emotion (happy, angry) was also computed. The reaction time data was screened and any outliers were removed based on each participant's trial-by-trial data. A reaction time trial was removed if it differed by 3 standard deviations above or below the participant's mean. The screened reaction times were used in the analyses.

Data analyses plan

The analyses for this study include linear and quadratic (curvilinear) analyses. Those findings are reported with loneliness alone and then when controlling for social anxiety and depression in the analyses. For the follow-up examination of significant linear and/or quadratic effects, the loneliness group includes people who were in the upper quartile of the loneliness scorers in the sample. In this study, a loneliness score of 50 or above was used as the lonely group.

Results

Eye-gaze manipulation check

Initially, to check whether the cognitive task manipulation worked on the current sample of participants, an ANOVA was conducted without including any loneliness or social anxiety or depression scores. Specifically, a 2 (emotion: happy, angry) x 5 (gaze angles: 0°, 2°, 4°, 6°, 8°) repeated measures ANOVA was conducted for the proportion of "looking at me" answers reported by the participant. A significant main effect for emotion was found ($F (1, 39) = 15.83$, $p < .001$, $\eta p^2 = .29$), with the higher proportion of "looking at me" answers for the happy face compared to angry face. A significant main effect of gaze angle was found ($F (4, 156) = 259.06$, $p < .001$, $\eta p^2 = .87$), with the proportion of "looking at me" answers decreasing as the faces were presented away from the participant. A significant interaction effect between emotion and gaze angle was also found ($F (4, 156) = 45.65$, $p < .001$, $\eta p^2 = .54$) with higher proportion of "looking at me" answers for the happy faces when faces were presented away from participant, and higher proportion of "looking at me" answers for the angry faces when faces were presented towards the participants. The above findings are consistent with the results reported in the study by Lobmaier et al, (2008), indicating that the emotion-gaze angle cognitive task manipulation worked with the current sample of participants.

Association between the effect of loneliness and eye-gaze (and emotion) perception

Linear and curvilinear (quadratic) regressions were conducted with mean loneliness scores as the predictor variable, and the mean proportion of "looking at me answers" for angry/happy faces across the five different gaze angles as the criterion variables. Table 4.1 shows the linear and quadratic regression results for loneliness and eye-gaze perception across the two emotions.

Table 4.1: Linear and curvilinear results of loneliness and eye-gaze perception of looking at me answers for five viewing angles for happy and angry emotions

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
Emotion Angry				
0°	-.248	.122	1.218	.247
2°	-.179	.269	.597	.579
4°	.052	.752	-.446	.683
6°	.022	.891	-.987	.365
8°	.113	.488	-1.05	.332
Emotion Happy				
0°	-.207	.200	1.368	.197
2°	-.267	.095	**2.301**	**.024**
4°	-.086	.598	.129	.906
6°	.133	.488	-.671	.537
8°	.122	.455	-.892	.410

Table 4.1 shows no significant linear or quadratic relations between loneliness and the five angry gaze viewing angles. However, a significant quadratic association was found between loneliness and the perception of 2 degree happy face (β = 2.301, p = .024), with very high and very low lonely adults more likely to perceive the directed gaze happy face as looking at them. A post-hoc independent samples t-test using a score of 50 or above as lonely (N = 10) and all other scorers as non-lonely (N = 30) failed to find a significant difference between the groups when perceiving the directed gaze happy face as looking at participants (t (38) = 1.281, p = .208). No other linear or quadratic relations were found between loneliness and the happy gaze viewing angles.

Overall reaction time as a function of emotion

Linear and curvilinear analyses were conducted between loneliness and overall reaction time for angry and happy emotions. No linear (β = -.263, p = .102) or quadratic (β = 1.434, p = .170) associations were found between loneliness and overall reaction time to happy faces. However, linear (β = -.298, p = .062) and quadratic (β = 1.861, p = .069) trends were observed between loneliness and overall reaction time to angry faces, but these were non-significant effects.

Controlling for social anxiety and depression in the analyses

Loneliness scores were correlated with the other three questionnaire measures. Pearson correlations showed significant positive associations between the loneliness measure UCLA and the depression measure CESD (r = .732, p < .001) and the social anxiety measure IAS (r = .611, p < .001). No significant correlations were found between the loneliness measure UCLA and social anxiety measure BFNE (r = .274, p = .087). The two significant questionnaire measures using total scores (IAS and CESD) were then entered in a regression analyses to create a standardized residual of the loneliness measure (see table 4.2) that was used in further analyses.

Table 4.2: Questionnaire measures entered into the regression analyses to create the loneliness residual

Questionnaire measure	Beta value	p value
CESD (depression)	.569	.000
IAS (social anxiety)	.319	.026

CESD depression and IAS social anxiety measures were used to form a standardized loneliness residual whilst controlling for depression and social anxiety.

Association between loneliness (controlling for social anxiety & depression) and eye-gaze (and emotion) perception

Linear and curvilinear analyses were conducted with mean loneliness scores (standardized residual with social anxiety and depression controlled) as the predictor variable, and the mean proportion of “looking at me answers” for angry/happy faces across the five different gaze angles as the criterion variables. Table 4.3 shows the linear and quadratic regression results for loneliness and eye-gaze perception across the two emotions.

Table 4.3: Linear and curvilinear results of loneliness and eye-gaze perception of looking at me answers for five viewing angles for happy and angry emotions with social anxiety and depression controlled

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
Emotion Angry				
0°	-.214	.190	-.050	.795
2°	**-.386**	**.015**	-.324	.066
4°	-.047	.775	**-.382**	**.044**
6°	.029	.863	-.309	.108
8°	.098	.551	-282	.141
Emotion Happy				
0°	-.053	.751	-.278	.148
2°	**-.340**	**.034**	-.159	.384
4°	-.041	.806	-.133	.493
6°	.160	.330	-.260	.173
8°	.168	.322	-.175	.362

With reference to table 4.3, loneliness was associated with the perception of 2 degrees angry face (linear: β = -.386, p = .015) with lonelier adults less likely to perceive the angry face as looking at them. A post hoc independent samples t-test failed to confirm a difference between the loneliness group (using standardized loneliness score of .522 as high lonely [N = 10] and all other scorers as non-lonely [N = 30]) and perception of directed angry face (t (38) = -1.748, p = .089). A quadratic association was found between loneliness and the perception of 4 degrees angry face (β = -.382, p = .044), with lonelier adults less likely to perceive the 4 degree angry face as looking at them. Post hoc independent samples t-test found no significant difference between the groups and perception of angry 4 degree face (t (38) = -.115, p = .9.09). Also, linear association was observed between loneliness and 2 degree happy face (β = -.340, p = .034), with lonelier adults less likely to perceive the directed happy face as looking at them. Post hoc independent samples t-test found a significant association between loneliness and directed happy face (t (38) = -2.019, p = .051), with lonely adults (M = .704) less likely to perceive the directed face as looking at them compared to non-lonely adults (M = .803).

Overall reaction time as a function of emotion

Linear and curvilinear analyses were conducted between loneliness and overall reaction time on judging whether the face was looking at the participant or not for angry and happy emotions. No linear (β = -.215, p = .188) or quadratic (β = -.025, p = .896) associations were found between loneliness and overall reaction time to happy faces. Similarly, no linear (β = -.227, p = .166) or quadratic (β = .000, p = .998) associations were found between loneliness and overall reaction to angry faces.

Conclusion from Study 2

When examination was focussed on the effect of loneliness, no significant associations were found for the subjective perception of eye-gaze to the angry faces. This suggests that lonely adults may not be hypervigilant to basic social cues such as emotion and eye-gaze. However, when social anxiety and depression were controlled in the analyses, loneliness was negatively associated with 2 degrees and 4 degrees eye-gaze perception of angry faces, but such an effect was not found for the directed 0 degrees face. This suggests that lonely adults may misjudge the eye-gaze of angry faces in ambiguous situations. This provides support for the hypervigilance to social threat hypothesis. Previous research indicates that lonely adults show poorer performance on a gaze task (Kunai et al, 2012) and feel more threatened in social situations (Cacioppo et al, 2000), and the findings reported here indicate that they may be on high alert for threats depicted as eye-gaze and emotions. However, the linear and curvilinear effects found in the study were not significant in follow up analyses. This could be because the current sample did not have many extreme loneliness scorers (above the score of 65) or the sample size of the groups was too small to detect an effect. Therefore, in the next set of studies (studies 3, 4 and 5), a screening protocol was initiated to recruit a wide distribution of loneliness scorers and to recruit extreme loneliness scorers at both end of the high/low spectrum.

Studies 3, 4, and 5 - Visual processing of lonely adults using eye-tracker methodology

Introduction

Cacioppo & Hawkley (2009) propose that loneliness is associated with hypervigilance to social threat. Different methodologies have been used to examine the cognitive biases of lonely people such as cognitive tasks (Cacioppo et al, 2000; Egidi et al, 2008), fMRI (Cacioppo et al, 2009) and eye-tracker (Qualter et al, 2013b) methods. However, only one study with children (Qualter et al, 2013b) and study 1 of this thesis have examined the hypervigilance to social threats using real life footage and eye-tracker technology.

The eye-tracker directly assesses selective attention and is an excellent tool in research as it assesses both early and late processing of attention continuously. This is a more accurate measure of attention in comparison to other cognitive tasks (i.e. dot probe and visual detection tasks) which fail to discriminate between earlier and later stages of attention processing (Bogels & Mansell, 2004). Furthermore, Goossens (2012) suggested that research examining attentional biases in loneliness using eye-tracker technology is needed because the hypervigilance to social threat hypothesis for loneliness may be explained by visual attention deployment that can be extended in viewing the social world.

In the eye-tracking literature, there are different patterns of attention processing that are noted as evidence for hypervigilance for threat. Initial vigilance and maintenance (hypervigilance) pattern of information processing is evident at earlier stages of viewing, whilst difficulty disengaging from threat stimuli (Buckner et al, 2010) and attentional avoidance pattern (Lange et al, 2011) of processing are evident at later timescales of viewing. Different patterns of attention processing are evident in loneliness. Findings from study 1 showed that lonely young adults show a pattern of initial hypervigilance followed by attentional avoidance of social rejection stimuli, while Qualter et al., (2013b) reported that lonely children show difficulty in disengaging from social rejection stimuli. Previous studies in the eye-tracker literature (i.e. Hermans et al., 1999) suggest the use of time-blocks to assess the patterns of attention deployment (hypervigilance demonstrated in the first 1000 milliseconds and avoidance or disengagement difficulties demonstrated in the next 2000 milliseconds time blocks) to the social threatening stimuli. Guided by this approach and the findings from study 1 which indicated that lonely adults only differed compared to non-lonely adults on viewing of the social threat stimuli within the first 2 seconds only – the next set of studies are focussed on the first four seconds of viewing time. Reference is also made to the extended viewing time in the results.

Aims for studies 3, 4, and 5

Study 3 aims to examine whether lonely adults are hypervigilant to social threat information when depicted as negative emotional facial expressions (e.g. angry). Study 4 aims to examine whether lonely adults are hypervigilant to social threats depicted as angry faces in a group context (e.g. when angry and smiling facial expressions are presented in a group of faces). Study 5 aims to examine whether lonely adults are hypervigilant to social threats that are depicted as static visual scenes showing instances of social rejection or social exclusion. The aim of these series of studies was to compare/contrast the results with eye-tracker studies that show lonely people are hypervigilant to socially rejecting information when viewing dynamic visual scenes (i.e. real video footage, Study 1; Qualter et al., 2013b: study 3).

Overall method for studies 3, 4, and 5

Participants

43 adults (8 males and 35 females) from a University in North West of England, UK, took part. Participants were either students or staff members at the University and were recruited by posters and the internal online recruitment system. The mean age of participants was 20 years and 2 months (SD = 3 months). The age range was restricted between 18 and 30 years, so that any effects found were not due to the factor of age. Prior research has found that age has an impact on attention tasks. Out of a total of 55 participants, 12 participants were removed from the analyses because they were above the age range of the study. For study 4, data from one participant was not included in the analyses due to technical errors. The same sample of participants took part in all three studies.

Measures

Loneliness: Loneliness was measured using the UCLA Loneliness scale (University of California, Los Angeles; Russell, 1996). This comprises 20 questionnaire items such as 'How often do you feel you are no longer close to anyone?' and 'How often do you feel left out?' Participants were required to indicate how often they felt the way described in each statement on a 4-point scale (Never, Rarely, Sometimes, Often). The scores for the scale range from 20 to 80. In the current sample, the scores ranged from 24 to 73. Mean scores were used in the analyses, with higher scores indicating higher levels of loneliness. The scale exhibited excellent internal consistency $\alpha = .95$.

Social anxiety: The Brief Fear of Negative Evaluation Scale (BFNE; Leary, 1983a) and Interaction Anxiousness Scale (IAS; Leary, 1983b; Leary & Knowalski, 1993) assessed the levels of social anxiety. The BFNE includes 12 questions and the IAS comprises of 15 questions; participants were asked to rate each statement on how characteristic it is of them using a 5 point scale (1 = not at all to 5 = extremely) for both scales. Higher scores indicated higher levels of social anxiety. The scales exhibited good internal consistency $\alpha = .91$ and $\alpha = .88$, respectively. Social anxiety was assessed using two questionnaire measures because both fear of negative evaluation and an anxiousness to interact with others are core features of social anxiety and either/both of these features could be related to loneliness. Thus, both measures were used as assessment measures in order to control for the correct features of social anxiety in the analyses.

Depression: The Center for Epidemiologic Studies Depression Scale (CES-D; Rudloff, 1977) was used to assess depressive symptomology. The scale included 20 questions requiring participants to indicate how often they felt the way described in the past week from four possible options (Rarely or none of the time; some or a little of the time; occasionally or a moderate amount of time; most or all of a time), but in the current study the item ‘I felt lonely’ was removed from the total score. Scores were summed and higher scores indicated higher levels of depressive symptoms. The scale exhibited excellent internal consistency $\alpha = .92$.

Eye-tracking device

Eyelink II model (with monocular recording at 500Hz) was used to track precise eye movements and foveal fixations for each participant. Data viewer was used to record eye movements and monitor the specified areas of interest. Attention was operationalized in terms of eye fixations. An eye fixation was recorded whenever the participant stopped or had a saccade in any of the areas of interest that were previously coded in the software.

Procedure

After informed consent was obtained, participants were asked to complete the measures in the experimental room at the University prior to the experimental tasks. Participants were asked to view three different picture studies like they would to do so when watching television. Eye responses (initial fixations, time spent on each picture) were recorded with the eye-tracker technology in real time. The three different picture studies were counterbalanced for the participants and the eye-tracker was calibrated for each study per participant.

Data analyses plan

The analyses for this study include linear and quadratic (curvilinear) analyses. The analyses are reported with loneliness alone and then reported with social anxiety and depression controlled in the analyses. For the follow-up examination of significant linear and/or quadratic effects, the loneliness group was created based on the extreme upper quartile of the loneliness scores in the sample. In studies 3, 4 and 5 a loneliness score of 60 or above was used as the lonely group. This was because the extreme scorers are likely to show differences in processing compared to other scorers on loneliness.

Controlling for social anxiety and depression in studies 3, 4 and 5

Loneliness scores were correlated with the other three questionnaire measures. Pearson correlations found significant positive associations between the loneliness measure UCLA and the depression measure CESD ($r = .736$, $p < .001$); social anxiety measure IAS ($r = .438$, $p < .005$); and the social anxiety measure BFNE ($r = .361$, $p < .05$). The three questionnaire measures using total scores (BFNE, IAS and CESD) were entered in a regression analyses to decide which measures would be used to create a standardized residual of the loneliness measure (see table 4.4).

Table 4.4: Questionnaire measures entered into the analyses to create the loneliness residual

Questionnaire measure	Beta value	p value
CESD (depression)	.680	.000
BFNE (social anxiety)	-.050	.697
IAS (social anxiety)	.302	.018

Table 4.4 shows that CESD depression and IAS social anxiety measures were only significant in the analyses. Therefore, these measures were used to form a standardized loneliness residual that controlled for depression and social anxiety in the analyses. The results are presented with loneliness only and then with controlling for social anxiety and depression.

Study 3 - Emotional faces and eye-tracker

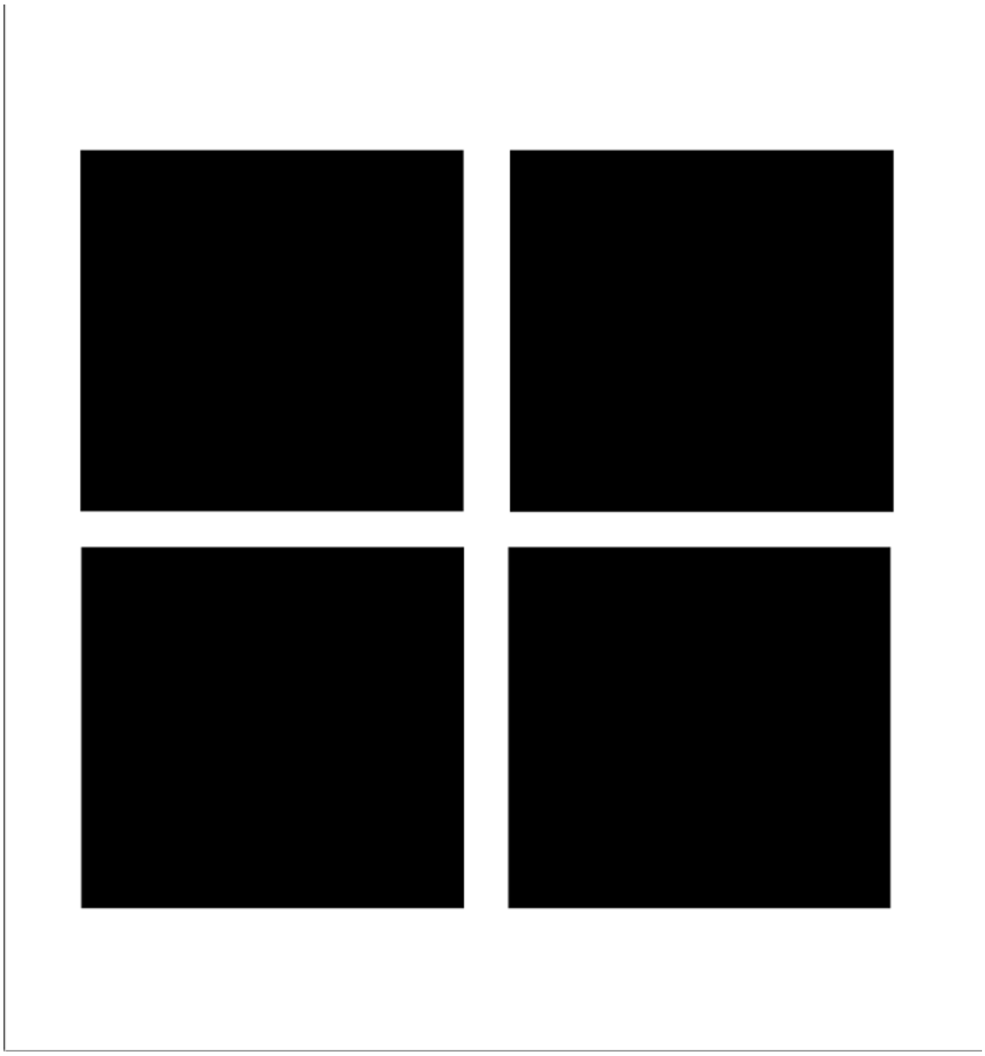
Specific introduction

Lonely adults attend to negative social information such as words and images of people differently to non-lonely adults (Cacioppo et al, 2009; Egidi et al, 2008). However, limited research has examined the processing of emotional information in loneliness. Previous research has found that individuals with fewer close friends were more accurate in identifying emotional expression and were more attentive to emotional vocal cues (Gardner et al, 2000). Consistent with the hypervigilance to social threat hypothesis, lonely adults may process negative emotions differently to non-lonely adults. Based on the negative cognitive biases of lonely adults; it can be expected that lonely adults are on high alert for social threats that are depicted as angry faces.

Experimental stimuli

Emotional facial stimuli were selected from the Karolinska directed emotional faces database (KDEF; Lundqvist, Flykt & Öhman, 1998). Four emotional expressions of the same person expressing happy, angry, afraid and neutral emotions were presented at the same time (refer to Appendix B for a list of the picture numbers). In total 24 pictures slides were created with equal number of male and females actors selected. The angry emotional expression was of interest as this may be depicted as a social threat for lonely adults. The picture location was randomised so that any of the pictures could be presented in any of the four locations. Each picture slide was viewed for 8 seconds followed by a 5 second blank screen and central fixation point (which participants were asked to focus on between trials). See Figure 4.2 for an example of a trial.

Figure 4.2: Example trial of study 3 showing a male expressing four different emotions (anger, fear, happy and neutral)



Data preparation

In the analyses the mean proportion of time fixating on each facial expression relative to the total captured fixation time was computed per time block across the 24 slides.

Results

Association between loneliness and attention to social threat (angry face)

Linear and curvilinear analyses were conducted, with loneliness as the predictor variable, and mean proportion of fixating time on angry faces for 8 blocks (each lasting 500 ms) of the first four seconds viewing time (and extended viewing time) as criterion variables. (See table 4.5)

Table 4.5: Linear and curvilinear results of loneliness and attention to angry faces in the first four seconds of viewing time (and extended viewing time)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	**.331**	**.030**	-.639	.579
100 ms	**.319**	**.037**	-.633	.584
1500 ms	**.326**	**.033**	-.663	.565
2000 ms	**.324**	**.034**	-.601	.602
2500 ms	**.311**	**.042**	-.661	.568
3000 ms	**.328**	**.032**	-.565	.624
3500 ms	**.321**	**.036**	-.468	.685
4000 ms	**.317**	**.038**	-.462	.690
Extended viewing				
4500 ms	**.310**	**.043**	-.400	.730
5000 ms	**.322**	**.035**	-.615	.594
5500 ms	**.330**	**.031**	-.537	.641
6000 ms	**.331**	**.030**	-.620	.590
6500 ms	**.303**	**.049**	-.362	.756
7000 ms	**.316**	**.039**	-.424	.714
7500 ms	**.341**	**.025**	-.363	.752
8000 ms	**.340**	**.026**	-.369	.748

Table 4.5 shows that loneliness was associated with attention to angry faces in the first 8 time blocks (i.e. 4 seconds). The linear effects suggest that

higher loneliness scores were associated with increased initial vigilance to angry face. No quadratic effects were found. During the remainder of viewing time, linear effects also suggest increased loneliness scores was associated with increased vigilance to the angry face.

To examine whether extreme loneliness scorers attended differently to the angry face, a 2 (lonely group: lonely *N* = 8, non-lonely *N* = 35) x 8 (time-blocks ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, 4000ms) repeated measures ANOVA found no significant main effects of time (F (3.538, 145.038) = 1.451, p = .225, ηp^2 = .034), or interaction effects of time x lonely group (F (3.538, 145.038) = .380, p = .794, ηp^2 = .009). However, a significant main effect was found (F (1, 41) = 5.188, p = .028, ηp^2 = .112), with means showing the lonely group (*M* = .20) spending a greater amount of viewing time on the angry face compared to the non-lonely group (*M* = .17).

To examine whether extreme loneliness scorers attended differently to the angry face during extended viewing, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 4500ms, 5000ms, 5500ms, 6000ms, 6500ms, 7000ms, 7500ms, 8000ms) repeated measures ANOVA found no significant main effects of time (F (1.641, 67.265) = .176, p = .796, ηp^2 = .004), or interaction effects of time x lonely group (F (1.641, 67.265) = .201, p = .775, ηp^2 = .005). However, a significant main effect was found (F (1, 41) = 5.764, p = .021, ηp^2 = .123), with means showing the lonely group (*M* = .20) spending a greater amount of viewing time on the angry face compared to the non-lonely group (*M* = .16).

Association between loneliness (controlling for social anxiety and depression) and attention to social threat (angry face)

Linear and curvilinear analyses were conducted, with the residual of loneliness as the predictor variable, and mean proportion of fixating time on angry faces for 8 blocks of the first four seconds viewing time (and extended viewing) as criterion variables. (See Table 4.6)

Table 4.6: Linear and curvilinear results of loneliness and attention to angry faces in the first four seconds of viewing time (and during extended viewing) controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.262	.090	.005	.973
100 ms	.267	.084	-.013	.936
1500 ms	.261	.091	.004	.981
2000 ms	.252	.104	-.010	.950
2500 ms	.230	.139	-.007	.967
3000 ms	.248	.107	.001	.995
3500 ms	.243	.117	.012	.939
4000 ms	.258	.095	.026	.869
Extended viewing				
4500 ms	.251	.104	.021	.892
5000 ms	.261	.090	.013	.935
5500 ms	.271	.078	.016	.917
6000 ms	.271	.078	.005	.976
6500 ms	.242	.117	.018	.908
7000 ms	.245	.113	.038	.811
7500 ms	.255	.079	.038	.808
8000 ms	.267	.084	.047	.766

Table 4.6 shows there were no linear or quadratic associations between loneliness and attention to angry faces. Similarly, for the remainder of the four seconds viewing time, no linear or quadratic associations were found to the angry face. This suggests that controlling for both social anxiety and depression in the analyses has an effect on the effect of loneliness and attention to angry face. Regression analyses controlling for social anxiety only found significant linear trends between the loneliness residual and attention to angry faces (βs < .269, ps > .081), but no quadratic associations (βs < -.129, ps > .509) in the total 8 second viewing time. Findings from the regression analyses controlling for depression showed significant linear associations between loneliness residual and attention to angry faces (βs < .306, ps > .046) but no quadratic associations (βs < .003, ps > .985) in the total 8 second viewing time. This

suggests that social anxiety was driving the effect between loneliness and attention to the angry face.

Attention to other faces

Two sets of linear and curvilinear analyses were conducted for each facial expression: one with loneliness as the predictor variable and another with the residual of loneliness as the predictor variable. The criterion variables were the mean proportion of fixating time on each face (afraid, happy, and neutral) for 8 blocks (each lasting 500 ms) of the first four seconds viewing time and during extended viewing. Tables 4.7 and 4.8 show the results for the fearful face, Tables 4.9 and 4.10 show the results for the happy face, and Table 4.11 and 4.12 show the results for the neutral face.

Table 4.7: Linear and curvilinear results of loneliness and attention to fearful faces in the first four seconds of viewing time (and extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.081	.603	-.644	.597
100 ms	.087	.578	-.631	.603
1500 ms	.079	.613	-.538	.658
2000 ms	.117	.453	-.556	.646
2500 ms	.097	.534	-.639	.598
3000 ms	.105	.502	-.608	.616
3500 ms	.083	.597	-.604	.619
4000 ms	.095	.544	-.537	.658
Extended viewing				
4500 ms	.089	.571	-.629	.604
5000 ms	.080	.608	-.700	.564
5500 ms	.085	.588	-.758	.532
6000 ms	.080	.612	-.707	.561
6500 ms	.093	.554	-.735	.545

7000 ms	.082	.601	-.761	.531
7500 ms	.049	.756	-.700	.565
8000 ms	.064	.684	-.716	.556

Table 4.8: Linear and curvilinear results of loneliness and attention to fearful faces in the first four seconds of viewing time (and extended viewing) controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.053	.734	.134	.410
100 ms	.052	.743	.143	.379
1500 ms	.055	.726	.144	.375
2000 ms	.079	.613	.130	.421
2500 ms	.063	.686	.127	.435
3000 ms	.076	.629	.118	.473
3500 ms	.061	.698	.104	.522
4000 ms	.064	.684	.084	.607
Extended viewing				
4500 ms	.063	.688	.089	.585
5000 ms	.049	.756	.087	.591
5500 ms	.037	.815	.093	.568
6000 ms	.047	.766	.105	.517
6500 ms	.050	.750	.113	.486
7000 ms	.045	.773	.091	.574
7500 ms	.018	.908	.098	.547
8000 ms	.012	.937	.079	.627

Table 4.9: Linear and curvilinear results of loneliness and attention to happy faces in the first four seconds of viewing time (and extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	-.085	.588	-1.589	.187
100 ms	-.092	.556	-1.608	.181
1500 ms	-.090	.568	-1.613	.180
2000 ms	-.108	.489	-1.583	.193
2500 ms	-.097	.538	-1.551	.197
3000 ms	-.103	.510	-1.528	.204
3500 ms	-.084	.591	-1.584	.188
4000 ms	-.091	.561	-1.586	.187
Extended viewing				
4500 ms	-.085	.589	-1.616	.179
5000 ms	-.082	.603	-1.508	.211
5500 ms	-.103	.510	-1.518	.207
6000 ms	-.091	.563	-.1461	.225
6500 ms	-.082	.603	-1.568	.193
7000 ms	-.091	.561	-1.556	.198
7500 ms	-.078	.621	-1.630	.176
8000 ms	-.079	.613	-1.624	.177

Table 4.10: Linear and curvilinear results of loneliness and attention to happy faces in the first four seconds of viewing time (and extended viewing) controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.002	.992	.001	.997
100 ms	-.001	.993	-.006	.973

1500 ms	-.002	.988	-.015	.928
2000 ms	-.019	.902	-.015	.925
2500 ms	-.012	.937	.003	.987
3000 ms	-.017	.912	.008	.961
3500 ms	.000	.998	.004	.979
4000 ms	.007	.965	.011	.945
Extended viewing				
4500 ms	.011	.945	.012	.940
5000 ms	.015	.925	.008	.960
5500 ms	-.001	.994	.018	.912
6000 ms	-.001	.995	.017	.919
6500 ms	.003	.985	.001	.994
7000 ms	.002	.990	.002	.991
7500 ms	.012	.941	-.011	.947
8000 ms	.014	.929	-.005	.975

Table 4.11: Linear and curvilinear results of loneliness and attention to neutral faces in the first four seconds of viewing time (and extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	**.365**	**.016**	**3.0245**	**.005**
100 ms	**.375**	**.013**	**3.039**	**.005**
1500 ms	**.374**	**.014**	**3.038**	**.005**
2000 ms	**.382**	**.011**	**2.959**	**.006**
2500 ms	**.383**	**.011**	**3.024**	**.005**
3000 ms	**.385**	**.011**	**2.927**	**.007**
3500 ms	**.380**	**.012**	**2.945**	**.006**
4000 ms	**.377**	**.013**	**2.881**	**.008**
Extended viewing				
4500 ms	**.379**	**.012**	**2.957**	**.006**

5000 ms	**.374**	**.014**	**3.004**	**.005**
5500 ms	**.385**	**.011**	**2.965**	**.006**
6000 ms	**.383**	**.011**	**2.961**	**.006**
6500 ms	**.381**	**.012**	**2.919**	**.007**
7000 ms	**.386**	**.011**	**2.921**	**.007**
7500 ms	**.373**	**.014**	**2.894**	**.008**
8000 ms	**.367**	**.016**	**2.892**	**.008**

Table 4.11 shows that loneliness was associated with attention to neutral faces in the first 8 time blocks (i.e. 4 seconds). The linear effects suggest that higher loneliness scores were associated with a greater amount of viewing time on the neutral face. Also, quadratic effects were found between loneliness and attention to neutral face suggesting that extreme loneliness scorers showed greater amount of viewing time on the neutral face. The same effects were found during extended viewing of the neutral face.

To further examine the linear and quadratic effects, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, 4000ms) repeated measures ANOVA found significant main effects of time (F (3.191, 130.184) = 3.739, p = .011, ηp^2 = .084), with means showing participants spending a greater amount of time on the neutral face in the first 2 second of viewing time. Similarly, a significant main effect of lonely group was observed (F (1, 41) = 6.216, p = .017, ηp^2 = .128), with means showing the lonely group (M = .25) spending a greater amount of viewing time on the neutral face compared to the non-lonely group (M = .19). There were no interaction effect of time x lonely group (F (3.191, 130.184) = .791, p = .508, ηp^2 = .019) found.

To examine whether extreme scorers of loneliness attended differently to the neutral face during extended viewing, a 2 (very lonely group: lonely, non-lonely) x 8 (time-blocks ending at 4500ms, 5000ms, 5500ms, 6000ms, 6500ms, 7000ms, 7500ms, 8000ms) repeated measures ANOVA found no significant main effects of time (F (3.404, 139.557) = .727, p = .157, ηp^2 = .040), or interaction effects of time x lonely group (F (3.404, 139.557) = 1.080, p = .364, ηp^2 = .026). However, a significant main effect of lonely group was found (F (1, 41) = 6.255, p = .016, ηp^2 = .132), with means showing the lonely group (M =

.25) spending a greater amount of viewing time on the neutral face compared to the non-lonely group (*M* = .19).

Table 4.12: Linear and curvilinear results of loneliness and attention to neutral faces in the first four seconds of viewing time (and extended viewing) controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.185	.236	-.099	.534
100 ms	.186	.233	-.098	.540
1500 ms	.188	.228	-.095	.550
2000 ms	.203	.193	-.083	.601
2500 ms	.211	.174	-.093	.560
3000 ms	.200	.198	-.097	.541
3500 ms	.200	.200	-.100	.530
4000 ms	.174	.265	-.102	.524
Extended viewing				
4500 ms	.176	.259	-.098	.539
5000 ms	.174	.285	-.085	.594
5500 ms	.191	.219	-.087	.587
6000 ms	.196	.209	-.090	.572
6500 ms	.205	.187	-.088	.580
7000 ms	.209	.179	-.086	.590
7500 ms	.210	.176	-.087	.584
8000 ms	.213	.169	-.078	.625

The table suggests that controlling for both social anxiety and depression in the analyses has an effect on the independent effect of loneliness and attention to neutral face. Regression analyses controlling for only social anxiety found significant linear (βs < .465, *p*s > .002) and significant quadratic associations (βs < .431, *p*s > .005) between loneliness residual and attention to neutral face in the total 8 second viewing time. Curvilinear analyses with controlling for only depression found no significant linear (βs < .095, ps > .545) and no significant quadratic associations (βs < -.138, ps > .379) between loneliness and attention to neutral face in the total 8 second viewing time. This suggests that depression was driving the effect between loneliness and attention to the neutral face.

First fixation

Chi-square analyses showed that extreme loneliness scorers and non-lonely participants were no more likely than chance to have their first fixation on the angry, fearful, happy or neutral face (χ^2 (3) = .346, p = .954). Similarly, using the residual of loneliness, chi-square analyses showed that extreme loneliness scorers and non-lonely participants were no more likely than chance to have their first fixation on the angry, fearful, happy or neutral face (χ^2 (3) = 2.478, p = .479).

Conclusion from study 3

The findings suggest that loneliness is associated with attention to social threats depicted as angry faces and that lonely adults show hypervigilance (i.e. greater amount of fixation time) towards these stimuli. However, once social anxiety and depression were statistically controlled in the analyses, this association was removed, suggesting that social anxiety and depression associated with loneliness were driving this effect. Therefore, once the social anxiety and depressive components of loneliness were controlled, lonely adults do not show hypervigilance to negative emotional information depicted on angry facial expressions. Further the results demonstrated that loneliness was associated with greater viewing time on the neutral face, but statistically controlling for social anxiety and depression in the analyses, the association was removed. However, Miller and Chapman (2001) argue that adding covariates into an analysis is not appropriate because it does not control group differences. This suggests that findings from study 3 should be interpreted with caution because removing the negative affect (social anxiety and depression) associated with loneliness indicates that the group variance left is not a true reflection of the loneliness construct, Therefore, the theoretical and practical implications of the findings should be based on loneliness only and not based on loneliness controlling for social anxiety and depression.

Study 4 - Faces in the crowd and eye-tracker

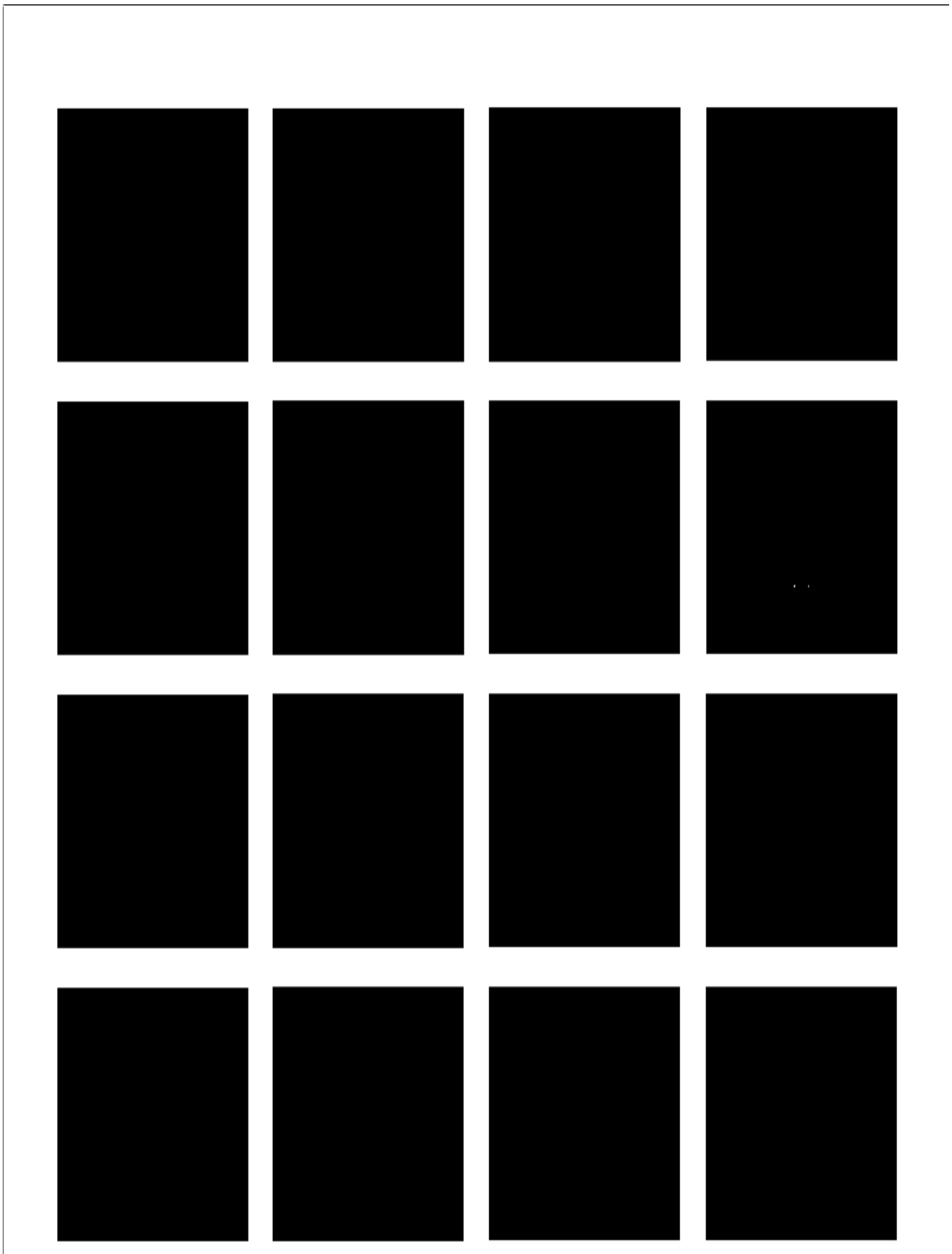
Specific introduction

The findings of study 3 indicate that loneliness is associated with a hypervigilance pattern of processing for social threats depicted as angry facial expressions. The next study expands that work to examine whether lonely adults are hypervigilant to angry faces in a group context. Typically during such a task, angry faces are found to pop out (i.e. anger superiority effect) at participants, with this effect being more prominent in individuals with symptoms of social anxiety and depression (Lange et al, 2011). The current study explores the role of social anxiety and depression components of loneliness.

Experimental stimuli

Photographs of 16 male individuals expressing happy and angry emotions were selected from the Karolinska directed emotional faces database (KDEF; Lundqvist, Flykt & Öhman, 1998). See Appendix B for a list of stimuli numbers used in the study. Photos were resized to 170 x 113 pixels and matrices of 16 (4x4). Happy and angry faces were selected to form a happy-angry crowd type and the stimuli were adapted from a previous study conducted by Lange et al., (2011). Male faces were used in the crowd stimuli because the speed of processing male faces is quicker (Lange et al, 2011). Seven different crowd type ratios were created by increasing the ratio of happy to angry faces in each crowd (16 faces); 14:2 (14 happy and 2 angry), 12:4, 10:6, 8:8, 6:10, 4:12, 2:14. The task included a total of 21 slides with 3 slides per ratio trial type (i.e. 3 slides of each of the 7 ratio trial types). Participants were presented with one of two pre-randomized crowds of each slide. Each picture slide was viewed for 8 seconds followed by a 5 second blank screen and central fixation point (which participants were asked to focus on between trials). Figure 4.3 shows an example trial of a crowd type.

Figure 4.3: Example stimuli used in study 4 showing an angry-happy crowd type (14 happy: 2 angry)



Data preparation

Time block analyses was not used in this study because the focus was on the examination of whether angry faces would capture the attention of lonely individuals in general and for this purpose time-blocks are not recommended (Armstrong & Olatunji, 2012). The mean proportion of overall fixation time on the angry faces (socially threatening stimuli) relative to the total captured fixation time for each crowd ratio was computed for analysis. Also, the mean proportion of overall fixating time on the happy faces relative to the total captured fixation time for each crowd ratio was computed for analysis.

Results

Loneliness and attention to angry faces and happy faces

Linear and curvilinear analyses were conducted, with loneliness as the predictor variable, and mean proportion of overall fixating time on the angry faces for the seven different ratios as criterion variables. Separate linear and curvilinear analyses were conducted for loneliness and mean proportion of overall fixating time on the happy faces for the seven different ratios (see table 4.13)

Table 4.13: Linear and curvilinear results of loneliness and attention to angry and happy faces in the seven different crowd types

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
Angry				
14 happy: 2 angry	**.416**	**.006**	**2.505**	**.018**
12 happy: 4 angry	**.486**	**.001**	1.440	.168
10 happy: 6 angry	**.414**	**.006**	1.887	.082
8 happy: 8 angry	.258	1.00	1.772	.124
6 happy: 10 angry	**.489**	**.001**	1.169	.284
4 happy: 12 angry	**.310**	**.046**	1.296	.260
2 happy: 14 angry	.261	.095	1.174	.312
Happy				
14 happy: 2 angry	-.119	.454	-.541	.652
12 happy: 4 angry	-.122	.442	.332	.782
10 happy: 6 angry	-.040	.202	.138	.909
8 happy: 8 angry	-.212	.178	-.604	.609
6 happy: 10 angry	-.286	.067	-.749	.517
4 happy: 12 angry	-.142	.371	-.721	.548

2 happy: 14 angry	-.105	.507	.812	.494

Table 4.13 shows that significant results were found for the angry faces in most of the different crowd types. To examine whether extreme loneliness scorers (score above 60) attended differently to the angry faces in the crowd stimuli, five one-way between ANOVAs were conducted with two levels of loneliness (lonely, non-lonely group). The five DVs were the mean proportion of overall fixating time on the angry faces in the 14 happy: 2 angry; 12 happy: 4 angry; 10 happy: 6 angry; 6 happy: 10 angry; 4 happy: 12 angry crowd types. Results showed significant main effects between loneliness and attention to angry faces in the 14 happy: 2 angry (F (1, 40) = 10.881, p = .002, ηp^2 = .214) and 12 happy: 4 angry crowd types (F (1, 40) = 8.112, p = .007, ηp^2 = .169), with means showing that lonely adults spending a greater amount of viewing time in the 14 happy: 2 angry and 12 happy:4 angry crowd types (*M* = .086; .054) compared to non-lonely adults (*M* = .047; .037). A significant main effect was observed for the 6 happy, 10 angry crowd type ((F (1, 40) = 6.256, p = .015, ηp^2 = .140), with means showing lonely adults spending a greater amount of viewing time on the angry face (*M* = .045) in comparison to non-lonely adults (*M* =.036). Also, a significant trend was found between loneliness and attention to angry faces in the 10 happy: 6 angry crowd types (F (1, 40) = 3.911, p = .055, ηp^2 = .089). A non-significant effect was found in the 4 happy: 12 angry crowd type (F (1, 40) = 1.829, p = 1.84, ηp^2 = .044).

First fixation

Chi-square analyses showed that extreme loneliness scorers and non-lonely participants were not more likely than chance to have their first fixation on the angry or happy face in the crowd stimuli (χ^2 (1) = 2.077 p = .150).

Loneliness and attention to angry and happy faces controlling for social anxiety and depression

Linear and curvilinear analyses were conducted, with the residual of loneliness as the predictor variable, and mean proportion of overall fixating time on the angry faces for the seven different ratios as criterion variables. Separate curvilinear analyses were conducted for loneliness and mean proportion of overall fixating time on the happy faces for the seven different ratios (see table 4.14)

Table 4.14: Linear and curvilinear results of loneliness and attention to angry and happy faces in the seven different crowd types controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
Angry				
14 happy: 2 angry	.185	.240	.004	.979
12 happy: 4 angry	.230	.143	.031	.845
10 happy: 6 angry	.137	.387	-.081	.616
8 happy: 8 angry	.225	.152	-.074	.644
6 happy: 10 angry	.223	.156	-.031	.846
4 happy: 12 angry	.038	.809	.110	.500
2 happy: 14 angry	.185	.240	.054	.738
Happy				
14 happy: 2 angry	-.009	.957	-.169	.299
12 happy: 4 angry	-.078	.626	.095	.559
10 happy: 6 angry	-.076	.632	.036	.825
8 happy: 8 angry	-.043	.789	-.047	.775
6 happy: 10 angry	-.024	.880	-.074	.650
4 happy: 12 angry	.031	.843	-.112	.493
2 happy: 14 angry	-.060	.707	-.212	.191

Table 4.14 shows that statistically controlling for social anxiety and depression in the analyses removed the effects found between loneliness and attention to angry faces in the crowd stimuli detailed in Table 4.13. The analyses were conducted again with a loneliness residual controlling for only social anxiety and a loneliness residual controlling for only depression. These analyses were conducted to investigate whether the effects were due to social anxiety, depression, or both. When the loneliness residual controlling for only social anxiety was used in the analyses, significant linear (and some quadratic) associations were found for loneliness and overall fixation time on the angry

faces in the seven crowd-types; 14 happy and 2 angry (Linear: β = .399, p = .009; Quadratic: β = .408, p = .012), 12 happy and 4 angry (Linear: β = .434, p = .004; Quadratic: β = .277, p = .088), 10 happy and 6 angry (Linear: β = .377, p = .014; Quadratic: β = .314, p = .059), 8 happy and 8 angry (Linear: β = .285, p = .058; Quadratic: β = .335, p = .051), 6 happy and 10 angry (Linear: β = .483, p = .001; Quadratic: β = .212, p = .183), 4 happy and 12 angry (Linear: β = .412, p = .007; Quadratic: β = .238, p = .150), 2 happy and 14 angry (Linear: β = .311, p = .045; Quadratic: β = .243, p = .159). Controlling for only depression in the loneliness residual no significant linear or quadratic associations were observed between loneliness and fixation time on the angry faces in any of the seven crowd types. This suggests that depression was causing the effect between loneliness and attention to angry faces in the crowd types.

First fixation using residual of loneliness

Chi-square analyses showed that extreme loneliness scorers were more likely than chance to have their first fixation on the angry face in the crowd stimuli and non-lonely participants were more likely than chance to have their first fixation on the happy face in the crowd stimuli (χ^2 (1) = 6.434 *p* = .011).

Conclusion from study 4

The results indicate that loneliness was associated with angry faces in a group context, with lonely adults showing an anger superiority effect in the crowd types that were predominantly in a group of happy faces. However, once controlling for the negative effects of loneliness (social anxiety and depression) the anger superiority effects of loneliness were removed and such results indicate that lonely adults do not show hypervigilance to angry faces when these faces are displayed in a group context. But, controlling for social anxiety and depression in the analyses with loneliness may not be appropriate because researchers could be removing variance central from the concept of loneliness.

Study 5 - Visual scenes and eye-tracker

Specific introduction

Empirical research suggests that loneliness is associated with issues of social rejection and exclusion (Jones et al, 1981). Studies 2, 3, and 4 provided evidence that lonely adults are on high alert for social threats depicted as angry facial expressions. However, study 1 and research by Qualter et al., (2013b) showed that loneliness was associated with visual attentional biases to real life video footage of social rejecting scenes suggesting that lonely people are hypervigilance to social threats depicted as social rejection stimuli. This assumption has not been examined using static images. Also, to date, no research has examined whether lonely adults are hypervigilant to social threats or threats in general using eye-tracker technology.

Experimental stimuli

Pictures were selected from the International affective picture system (IAPS; Lang, Bradley & Cuthbert, 2008). Four picture types were presented at the same time on one slide depicting: (1) physical threat (violence, aggression); (2) social threat (rejection, lone individuals); (3) social positive (social interactions or social relationships); and (4) neutral (field, sky) images. Valence ratings (1 = unpleasant, 9 = pleasant) from the IAPS manual of the stimuli for each picture type were as follows: (1) 3.09; (2) 3.68; (3) 7.05; (4) 7.08. See Appendix B for a list of IAPS numbers of stimuli used in the study and see Figure 4.4 for an example of stimuli of a trial. An additional 18 images were included for the social threat category which were specifically chosen to depict instances of rejection behaviour. Valence ratings for these additional images were carried out by an independent sample of 118 undergraduate students (age range 19 - 44 years; 87 females and 28 males). The additional images were classed as unpleasant (M = 3.69; 1 = pleasant, 5 = unpleasant) and rated as a good example of rejecting behaviour (M = 2.49; 1 = good example, 5 = weak example). The study included a total of 24 slides (with 4 pictures, one each of the picture categories). The picture location was randomised so that any of the pictures could be presented in any of the four locations. Each picture slide was viewed for 8 seconds followed by a 5 second blank screen and central fixation point (which participants were asked to focus on between trials).

Figure 4.4: Example stimuli used in Study 5 showing images of social threat, physical threat, neutral and social positive

[redacted]

Data preparation

Similar to data preparation in study 3, time blocks were used to assess attention patterns over time. In the analysis the mean proportion of time fixating on each picture category (social threat, physical threat, social positive, neutral) relative to the total captured fixation time was computed per time block.

Results

Association between loneliness and attention to social threat stimuli

Linear and curvilinear analyses were conducted, with loneliness as the predictor variable, and mean proportion of fixating time on the social threat stimuli for 8 blocks (each lasting 500 ms) of the first four seconds viewing time as criterion variables. (See table 4.15)

Table 4.15: Linear and curvilinear results of loneliness and attention to social threat stimuli in the first four seconds of viewing time and during extended viewing

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	**.374**	**.014**	1.402	.211
100 ms	**.368**	**.015**	1.445	.198
1500 ms	**.366**	**.016**	1.496	.183
2000 ms	**.358**	**.018**	1.396	.216
2500 ms	**.354**	**.020**	1.486	.188
3000 ms	**.363**	**.017**	1.369	.225
3500 ms	**.365**	**.016**	1.496	.183
4000 ms	**.365**	**.016**	1.377	.222
Extended viewing				
4500 ms	**.359**	**.018**	1.378	.222
5000 ms	**.364**	**.016**	1.387	.218
5500 ms	**.361**	**.017**	1.448	.199
6000 ms	**.379**	**.012**	1.387	.215
6500 ms	**.374**	**.013**	1.461	.192
7000 ms	**.381**	**.012**	1.420	.204
7500 ms	**.363**	**.017**	1.492	.185
8000 ms	**.363**	**.017**	1.585	.158

Table 4.15 shows that loneliness was associated with attention to social threat in the first 8 time blocks (i.e. 4 seconds) and during the remainder of viewing time. The linear effects suggest that higher loneliness scores were associated with a greater amount of viewing time on the social threat stimuli.

To examine whether extreme loneliness scorers attended differently to the social threat stimuli, a 2 (lonely group: lonely N = 8, non-lonely N = 35) x 8 (time-blocks ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, 4000ms) repeated measures ANOVA was conducted. Results showed significant main effects of time (F (3.363, 137.900) = 11.205, p = .000, ηp^2 = .215), with means showing all participants spending less time on the social threat stimuli in the first 2 seconds of viewing time. Also, a significant main effect of lonely group was observed (F (1, 41) = 14.890, p = .000, ηp^2 = .266), with means showing the very lonely group (M = .24) spending a greater amount of viewing time on the social threat stimuli compared to the non-lonely group (M = .18). No interaction effect was found for time x lonely group (F (3.363, 137.900) = .379, p = .791, ηp^2 = .001).

To examine whether extreme loneliness scorers attended differently to the social threat stimuli during extended viewing, a 2 (lonely, non-lonely) x 8 (time-blocks ending at 4500ms, 5000ms, 5500ms, 6000ms, 6500ms, 7000ms, 7500ms, 8000ms) repeated measures ANOVA found no significant main effects of time (F (3.293, 135.033) = .471, p = .721, ηp^2 = .011), or interaction effects of time x lonely group (F (3.293, 135.033) = .603, p = .630, ηp^2 = .014). However, a significant main effect was found for lonely group (F (1, 41) = 14.930, p = .000, ηp^2 = .267), with means showing the lonely group (M = .23) spending a greater amount of viewing time on the social threat stimuli compared to the non-lonely group (M = .17).

Association between loneliness and attention to social threat stimuli controlling for social anxiety and depression

Linear and curvilinear analyses were conducted, with residual of loneliness as the predictor variable, and mean proportion of fixating time on social threat stimuli for 8 blocks of the first four seconds viewing time (and extended viewing) as criterion variables with social anxiety and depression controlled in the analyses. (See table 4.16)

Table 4.16: Linear and curvilinear results of loneliness and attention to social threat stimuli in the first four seconds of viewing time and during extended viewing controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	**.414**	**.006**	.122	.407
100 ms	**.402**	**.008**	.105	.482
1500 ms	**.404**	**.007**	.101	.497
2000 ms	**.410**	**.006**	.097	.512
2500 ms	**.403**	**.007**	.106	.476
3000 ms	**.420**	**.005**	.03	.484
3500 ms	**.407**	**.007**	.116	.435
4000 ms	**.402**	**.008**	.087	.560
Extended viewing				
4500 ms	**.397**	**.008**	.087	.559
5000 ms	**.394**	**.009**	.083	.577
5500 ms	**.407**	**.007**	.073	.623
6000 ms	**.396**	**.009**	.065	.663
6500 ms	**.405**	**.007**	.055	.713
7000 ms	**.396**	**.008**	.071	.634
7500 ms	**.400**	**.008**	.081	.589
8000 ms	**.401**	**.008**	.091	.540

Table 4.16 shows that loneliness when controlling for social anxiety and depression was associated with attention to social threat in the first 8 time blocks (i.e. 4 seconds) and during extended viewing. The linear effects suggest that higher loneliness scores were associated with a greater amount of viewing time on the social threat stimuli whilst controlling for social anxiety and depression.

To examine whether extreme loneliness scorers attended differently to the social threat stimuli, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, 4000ms) repeated measures ANCOVA with social anxiety and depression as covariates was conducted. Results showed no significant main effect of time (*F* (3.433, 133.879) = .681, *p* = .585, ηp^2 = .017). However, a significant main effect of lonely group was observed (*F* (1, 39) = 16.936, *p* = .000, ηp^2 = .308), with means showing the lonely group (*M* = .26) spending a greater amount of viewing time on the social threat stimuli compared to the non-lonely group (*M* = .18). No interaction effect was found for time x lonely group (*F* (3.433, 133.879) = .428, *p* = .759, ηp^2 = .011).

To examine whether extreme loneliness scorers attended differently to the social threat stimuli during extended viewing, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 4500ms, 5000ms, 5500ms, 6000ms, 6500ms, 7000ms, 7500ms, 8000ms) repeated measures ANCOVA with social anxiety and depression as covariates was conducted. Results showed no significant main effect of time (*F* (3.121, 121.731) = .379, *p* = .776, ηp^2 = .010). However, a significant main effect of lonely group was observed (*F* (1, 39) = 16.259, *p* = .000, ηp^2 = .294), with means showing the lonely group (*M* = .25) spending a greater amount of viewing time on the social threat stimuli compared to the non-lonely group (*M* = .18). No interaction effect was found for time x lonely group (*F* (3.121, 121.731) = .670, *p* = .578, ηp^2 = .017).

Attention to other picture categories

Two sets of linear and curvilinear analyses were conducted, one with loneliness as the predictor variable, and another with the residual of loneliness as the predictor variable. The criterion variables were the mean proportion of fixating time on each picture category (physical threat, social positive, neutral) for 8 blocks (each lasting 500 ms) of the first four seconds viewing time and during extended viewing. Tables 4.17 and 4.18 shows the results for the physical threat stimuli, Tables 4.19 and 4.20 show the results for the social positive images, and Tables 4.21 and 4.22 show the results for the neutral images.

Table 4.17: Linear and curvilinear results of loneliness and attention for physical threat in the first four seconds of viewing time (and extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.284	.065	1.409	.225
100 ms	.294	.056	1.313	.257
1500 ms	.293	.056	1.276	.271
2000 ms	.296	.054	1.231	.288
2500 ms	.272	.077	1.465	.208
3000 ms	.266	.085	1.511	.194
3500 ms	.269	.081	1.449	.214
4000 ms	.259	.094	1.342	.251
Extended viewing				
4500 ms	.277	.072	1.284	.270
5000 ms	.292	.057	1.358	.241
5500 ms	.289	.060	1.317	.256
6000 ms	.287	.062	1.279	.271
6500 ms	.286	.063	1.271	.274
7000 ms	.282	.067	1.220	.294
7500 ms	.282	.067	1.081	.353
8000 ms	.261	.091	1.150	.326

The linear trends suggest that higher loneliness scores were associated with a greater amount of viewing time on the physical threat images. However, these effects were non-significant ($p > .05$).

Table 4.18: Linear and curvilinear results of loneliness and attention to physical threat images in the first four seconds of viewing time (and during extended viewing controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.153	.327	-.261	.099
100 ms	.163	.296	-.255	.107
1500 ms	.155	.322	-.258	.103
2000 ms	.161	.304	-.259	.102
2500 ms	.140	.370	-.261	.099
3000 ms	.155	.320	-.255	.107
3500 ms	.154	.325	-.274	.083
4000 ms	.144	.358	-.298	.079
Extended viewing				
4500 ms	.182	.243	-.285	.069
5000 ms	.178	.255	-.285	.070
5500 ms	.179	.250	-.260	.099
6000 ms	.187	.231	-.250	.114
6500 ms	.179	.250	-.245	.121
7000 ms	.175	.262	-.249	.115
7500 ms	.172	.271	-.262	.097
8000 ms	.174	.264	-.278	.077

Table 4.19: Linear and curvilinear results of loneliness and attention to social positive images in the first four seconds of viewing time (and during extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	-.192	.218	.193	.872
100 ms	-.197	.205	.299	.803

1500 ms	-.171	.273	.211	.861
2000 ms	-.173	.268	.416	.729
2500 ms	-.154	.325	.231	.848
3000 ms	-.151	.332	.239	.843
3500 ms	-.169	.279	.153	.899
4000 ms	-.153	.326	.196	.871
Extended viewing				
4500 ms	-.167	.285	.189	.875
5000 ms	-.190	.221	.207	.863
5500 ms	-.181	.245	.130	.914
6000 ms	-.201	.195	.133	.912
6500 ms	-.196	.208	.210	.860
7000 ms	-.210	.175	.344	.773
7500 ms	-.190	.223	.504	.674
8000 ms	-.165	.290	.492	.683

Table 4.20: Linear and curvilinear results of loneliness and attention to social positive images in the first four seconds of viewing time (and during extended viewing) controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	-.066	.674	-.192	.234
100 ms	-.069	.660	-.188	.250
1500 ms	-.051	.745	-.184	.254
2000 ms	-.067	.672	-.181	.281
2500 ms	-.041	.792	-.171	.274
3000 ms	-.053	.737	-.175	.278
3500 ms	-.052	.740	-.158	.329
4000 ms	-.036	.821	-.158	.328
Extended viewing				

4500 ms	-.038	.806	-.179	.269
5000 ms	-.033	.834	-.194	.230
5500 ms	-.046	.772	-.201	.213
6000 ms	-.065	.679	-.189	.242
6500 ms	-.066	.675	-.173	.285
7000 ms	-.076	.627	-.178	.270
7500 ms	-.060	.702	-.167	.302
8000 ms	-.056	.723	-.151	.350

Table 4.21: Linear and curvilinear results of loneliness and attention to neutral images in the first four seconds of viewing time (and extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	-.289	.060	-.304	.795
100 ms	-.288	.062	-.361	.759
1500 ms	-.287	.062	-.319	.785
2000 ms	-.285	.064	-.344	.769
2500 ms	-.293	.057	-.387	.740
3000 ms	-.295	.055	-.346	.767
3500 ms	-.284	.065	-.320	.785
4000 ms	-.298	.052	-.219	.851
Extended viewing				
4500 ms	-.290	.060	-.177	.880
5000 ms	-.287	.062	-.222	.850
5500 ms	-.291	.058	-.269	.818
6000 ms	-.290	.060	-.274	.815
6500 ms	-.294	.056	-.262	.822
7000 ms	-.281	.068	-.375	.749
7500 ms	-.287	.062	-.373	.750
8000 ms	-.296	.059	-.362	.757

The linear trend suggests that higher loneliness scores were associated with less amount of viewing time on the neutral images. However, these effects were not significant (p >.05).

Table 4.22: Linear and curvilinear results of loneliness and attention to neutral images in the first four seconds of viewing time and extended viewing controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	**-.335**	**.028**	.026	.864
100 ms	**-.332**	**.030**	.026	.867
1500 ms	**-.329**	**.031**	.028	865
2000 ms	**-.334**	**.029**	.024	.878
2500 ms	**-.347**	**.023**	.014	.929
3000 ms	**-.349**	**.022**	.012	.937
3500 ms	**-.349**	**.026**	.018	.907
4000 ms	**-.346**	**.023**	.035	.818
Extended viewing				
4500 ms	**-.361**	**.017**	.054	.724
5000 ms	**-.357**	**.019**	.067	.661
5500 ms	**-.344**	**024**	.062	.684
6000 ms	**-.340**	**.026**	.056	.714
6500 ms	**-.340**	**.026**	.050	.742
7000 ms	**-.322**	**.035**	.044	.775
7500 ms	**-.332**	**.029**	.033	.829
8000 ms	**-.338**	**.027**	.026	.865

Table 4.22 shows that the residual of loneliness was associated with attention to neutral images in the first 8 time blocks (i.e. 4 seconds) and during extended viewing. The linear effects suggest that higher loneliness scores were associated with a less amount of viewing time on the neutral stimuli whilst controlling for social anxiety and depression.

To examine whether extreme loneliness scorers attend differently to neutral stimuli, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, 4000ms) repeated measures ANCOVA with social anxiety and depression as covariates was conducted. Results showed no significant main effect of time (F (2.193, 85.514) = .886, p = .579, ηp^2 = .022), main effect of lonely group (F (1, 39) = 2.164, p = .149, ηp^2 = .053), interaction effect for time x lonely group (F (2.193, 85.514) = .649, p = .539, ηp^2 = .016).

To examine whether extreme loneliness scorers attend differently to neutral stimuli during extended viewing, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 4500ms, 5000ms, 5500ms, 6000ms, 6500ms, 7000ms, 7500ms, 8000ms) repeated measures ANCOVA with social anxiety and depression was conducted. Results showed no significant main effect of time (F (3.096, 120.725) = .081, p = .973, ηp^2 = .002), main effect of lonely group (F (1, 39) = 2.099, p = .155, ηp^2 = .051), interaction effect for time x lonely group (F (3.096, 120.725) = .950, p = .421, ηp^2 = .024).

Loneliness and attention to social threat metric

A social threat metric was created to examine whether loneliness was associated with viewing of social threat stimuli while controlling for viewing of all threatening pictures. Based on reaction time literature (Ede, Lange & Maris, 2012), the metric was used to control for any differences in overall threat responding. This new variable was calculated for each participant for each of the first 8 time-blocks (each 500ms) and for extending viewing as average viewing times for social threat pictures minus the average viewing time for physical threat pictures divided by the sum of average viewing time for social threat and average viewing time for physical threat pictures. That calculation was also based on previous literature (Singer, Eapen, Grillon, Ungerleider & Hendler, 2012). Linear and curvilinear analyses were then conducted, with loneliness as the predictor variable, and mean proportion of fixating time on the social threat metric for 8 blocks (each lasting 500 ms) of the first four seconds viewing time and extended viewing as criterion variables (see Table 4.23). Similar analyses were conducted with the residual of loneliness as the predictor variable (see Table 4.24).

Table 4.23: Linear and curvilinear results of loneliness and attention to social threat metric in the first four seconds of viewing time (and extended viewing)

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.132	.399	.458	.705
100 ms	.115	.463	.567	.640
1500 ms	.109	.485	.646	.594
2000 ms	.100	.522	.594	.624
2500 ms	.118	.452	.578	.669
3000 ms	.139	.372	.396	.743
3500 ms	.126	.421	.566	.640
4000 ms	.138	.378	.481	.691
Extended viewing				
4500 ms	.119	.447	.513	.672
5000 ms	.116	.459	.461	.704
5500 ms	.111	.478	.543	.654
6000 ms	.133	.398	.491	.697
6500 ms	.131	.404	.551	.648
7000 ms	.133	.396	.554	.647
7500 ms	.121	.440	.777	.520
8000 ms	.139	.374	.808	.898

Table 4.23 shows loneliness was not associated with the social threat metric. This suggests that higher loneliness scores were not related to a greater amount of viewing time on the social threat stimuli while controlling for individual viewing of threatening images.

Table 4.24: Linear and curvilinear results of loneliness and attention to social threat metric in the first four seconds of viewing time (and extended viewing) controlling for social anxiety and depression

	Linear analyses		Quadratic analyses	
	Beta value	p value	Beta value	p value
End time block				
500 ms	.230	.138	.326	.034
100 ms	.209	.178	.309	.047
1500 ms	.212	.172	.309	.047
2000 ms	.216	.184	.299	.055
2500 ms	.229	.140	.310	.045
3000 ms	.244	.115	.291	.060
3500 ms	.216	.164	.340	.027
4000 ms	.228	.142	.289	.063
Extended viewing				
4500 ms	.191	.220	.313	.045
5000 ms	.200	.198	.304	.051
5500 ms	.208	.181	.269	.085
6000 ms	.198	.203	.244	.122
6500 ms	.218	.151	.229	.145
7000 ms	.197	.205	.270	.085
7500 ms	.209	.178	.299	.055
8000 ms	.206	.185	.325	.036

Table 4.24 indicates that those individuals scoring higher on loneliness spent a greater amount of viewing time on the social threat stimuli metric controlling for overall viewing time of threatening pictures.

To further examine whether extreme loneliness scorers attend differently using the social threat metric, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, 4000ms) repeated measures ANCOVA with social anxiety and depression as covariates was conducted. Results showed no significant main effect of time (F (3.514, 137.056) = .694, p = .579, ηp^2 = .017). However, a significant main effect of lonely group (F (1, 39) = 3.281, p = .027, ηp^2 = .119) was found, with means showing the lonely group (M = .027) spending a greater amount of viewing time on the social threat controlling for threat response in general, compared to the non-lonely group (M = -.096). No interaction effect was found for time x lonely group (F (3.514, 137.056) = .147, p = .951, ηp^2 = .004).

To further examine whether extreme loneliness scorers attend differently using the social threat metric, a 2 (lonely group: lonely, non-lonely) x 8 (time-blocks ending at 4500ms, 5000ms, 5500ms, 6000ms, 6500ms, 7000ms, 7500ms, 8000ms) repeated measures ANCOVA with social anxiety and depression as covariates was conducted. Results showed no significant main effect of time (F (3.258, 127.056) = .635, p = .606, ηp^2 = .016). However, a significant main effect of lonely group (F (1, 39) = 4.467, p = .041, ηp^2 = .103) was found, with means showing the lonely group (M = .021) spending a greater amount of viewing time on the social threat controlling for threat response in general, compared to the non-lonely group (M = -.087). No interaction effect was found for time x lonely group (F (3.258, 127.056) = .295, p = .844, ηp^2 = .008).

First fixation

Chi-square analyses showed that extreme loneliness scorers and non-lonely participants were no more likely than chance to have their first fixation on the social threat, physical threat, social positive or neutral images (χ^2 (1) = .008, p = .931). Interestingly, the majority of all participants in the study had their mean first fixation on the social threat stimuli with only a few participants having their mean first fixation on the social positive image. Using the residual of loneliness controlling for social anxiety and depression, chi-square analyses showed that extreme loneliness scorers and non-lonely participants were no more likely than chance to have their first fixation on the social threat, physical threat, social positive or neutral images (χ^2 (1) = 1.381, p = .240).

Conclusion for study 5

Loneliness was associated with lonely adults viewing social threat images for a greater duration across time. This suggests that lonely adults are hypervigilant to social threats linked to social rejection. The results did not change when social anxiety and depression were controlled in the analyses, indicating these effects were driven by loneliness and not due to negative affect associated with loneliness. Furthermore, the effect of loneliness controlling for social anxiety and depression was associated with less viewing time of neutral images across time. However, loneliness was not found to be associated with viewing the social positive and physical threat images.

Discussion of studies 2, 3, 4, and 5

The current sets of studies have systematically examined the hypervigilance to social threat hypothesis proposed by Cacioppo and Hawkley (2009). The studies use cognitive paradigms and eye-tracker methodology. In this section, results are discussed with the effect of loneliness across the four studies first and then results are discussed with loneliness controlling for social anxiety and depression.

Results for loneliness. Study 2 did not find that loneliness was associated with hypervigilance to social threats, when participants were asked to decide whether a face with different gaze angles was looking at them or not. This suggests that lonely adults do not view directed eye-gaze of angry faces (a cue used in basic social perception) as threatening by showing either vigilance or avoidance of that stimuli. Study 3, using stimuli of emotional expressions and eye-tracker methodology, found that loneliness was associated to hypervigilance to social threats depicted as negative facial expressions. Specifically, adults scoring high on loneliness (very lonely adults) viewed the angry face for longer durations in the first four seconds of viewing time and during extended viewing compared to those scoring low on loneliness (non-lonely adults). This finding reflects the fact that very lonely adults are hypervigilant to the angry facial expressions, but also that they find it difficult to disengage from the stimuli. Interestingly, very lonely adults showed a similar pattern of viewing behaviour for the neutral facial expressions and viewed these images for longer duration across the full viewing time period. Loneliness was not found to be associated with the viewing of happy or afraid facial expressions suggesting that threatening information is more salient to lonely adults, even when four emotions are presented at once. The above finding that loneliness is not associated with vigilance to happy faces suggests lonely people do not monitor the social environment for positive social cues (Gardner et al, 2005; SMS theory). Study 4 using crowd stimuli with differing ratios of happy/angry facial expressions found that very lonely adults were more likely to fixate for longer durations over the full viewing period on the angry faces in predominantly crowds of happy faces. This suggests loneliness is associated with anger superiority effect in crowd stimuli (i.e. reflects a pattern of hypervigilance), where angry faces appear to capture the attention of lonely adults.

Findings from study 5 indicate that lonely adults show a specific hypervigilance to social threats linked to social rejection and that they were unable to relocate their attention in the first four seconds of viewing time and during extended viewing. There were no differences observed between loneliness and viewing time for physical threat, neutral and social positive images when presented at the same time. The latter finding suggests that lonely adults are not attuned to or process both positive and negative social cues in the social environment as proposed by Gardner et al (2005). This study supports Cacioppo and Hawkley's (2009) model indicating that the hypervigilance pattern of processing is specific to social threats and not to those threats that are linked to violence and aggression or social positive scenes.

A different pattern of visual processing was observed across study 1 and study 5. Findings from study 1 showed that lonely adults were hypervigilance to social threats for the first two seconds and then avoided real life video footage including scenes of social rejection, while study 5 found that lonely adults fixed their attention on the social threat of static pictures for longer durations during the viewing period (i.e. disengagement difficulties). These findings from study 5 were similar to that found amongst lonely children, who also had difficulty in disengaging from real life footage of socially threatening stimuli (Qualter et al, 2013b: study 3). One possible reason for finding a different attention processing bias to social threat stimuli for study 1 and study 5 is that not all lonely adults in those studies attended in the same way: the lonely adults in study 1 may have higher levels of loneliness or prolonged loneliness, whilst the lonely adults in study 5 may have felt lonely for a shorter period of time. Future work should examine these cognitions by using longitudinal research methods.

Results for loneliness controlling for social anxiety and depression. Findings from study 2 suggest when controlling for social anxiety and depression, loneliness is associated with an ambiguity for directed eye-gaze of angry faces. These results suggest that lonely adults are not hypervigilant to social threats depicted as basic social cues and instead they show an avoidance of the eye-gaze cue. Findings from study 3 when controlling for social anxiety and depression show that loneliness is not associated with hypervigilance to social threats depicted as negative facial expressions (i.e. anger) nor that loneliness is associated with the other basic emotions (e.g. afraid, happy, neutral). Study 4 when controlling for social anxiety and depression indicates that loneliness was not associated with hypervigilance to social threats displayed in a crowd of happy faces (i.e. anger superiority effect). This indicates that the finding of lonely adults showing hypervigilance to social threats depicted as angry facial expressions (study 3: effect of loneliness) and displayed in crowd stimuli (study 4: effect of loneliness) was caused by the negative affect of social anxiety and depression associated with loneliness. These effects were not found when social anxiety and depression were controlled in the analyses.

Study 5 when controlling for social anxiety and depression showed that loneliness is associated with a specific attentional bias that is linked to rejection stimuli. Findings suggest that social threats are conceptualized as stimuli showing rejecting behavior for lonely adults and they are unable to relocate their attention from these stimuli. These findings support those from recent eye-tracker work (Qualter et al, 2013b), in which lonely children found it difficult to disengage from socially threatening stimuli and lonely young adults show initial vigilance to socially threatening video footage (study 1). Also, adults scoring high on loneliness fixated longer on the social threat stimuli while controlling for overall viewing behaviour of threat stimuli. This suggests that loneliness is associated with a hypervigilance to social threat linked to social rejection stimuli and not to threats (i.e. violence, aggression) in general. But that finding was only observed with loneliness and not when social anxiety and depression were controlled in the analyses. Interestingly, using the social threat metric yielded a weaker effect between loneliness and attention to social threat stimuli in comparison to when controlling for social anxiety and depression. This suggests that controlling for the negative affect of loneliness may be more relevant for analyses than controlling for overall threat responding.

Strengths and limitations

One strength of the current set of studies is the ability to control for the negative affect (social anxiety and depression) associated with loneliness in the analyses. This is important because social anxiety/depression are related to the construct of loneliness and cognitive biases. Future work should present the results with the effect of loneliness and the same results when controlling for social anxiety and depression, so researchers are able to indicate which construct is driving the effect where one is found.

One limitation of the current studies is that the age range was limited to 18 to 30 years. It is possible that older lonely adults attend and show a different pattern of attentional bias to social threat stimuli. Therefore, eye-tracker research should be conducted to examine this hypervigilance in older samples because this may differ across development.

The current set of studies does not examine gender differences. This is because differences in visual processing of pictures and attention are not expected between males and females. Previous cognitive research did not find any differences between genders (Weiss, Kemmler, Deisenhammer, Fleischhacke & Delazer, 2003). In addition, the sample of all three studies were predominantly of a female population with an unequal gender split, so gender differences between males and females could not be examined.

Theoretical implications of the current set of studies

Some of the findings from studies 2 to 5 (not controlling for social anxiety and depression) are consistent with the model of loneliness that proposes lonely people display biased attention for social threat. The current studies extend Cacioppo and Hawkley's model by examining the hypervigilance to social threat hypothesis with a cognitive paradigm and finding evidence for visual attention biases (linked to rejection) in lonely adults, using eye-tracker methodology. Study 2 suggests that lonely adults are not hypervigilance to social threats depicted as eye-gaze and that they do not have difficulty in processing this social cue. Findings from studies 3 and 4 support the idea that lonely adults are hypervigilant to social threats depicted as angry faces. The findings from study 5 are in line with the model as they indicate that lonely adults show visual attentional biases to social rejection images. Studies 3, 4 and 5 provide evidence for Cacioppo and Hawkley's theoretical model and support the notion that loneliness is associated with social information processing biases to both angry faces and scenes of social rejection. However, none of the above studies support the social monitoring system proposed by Gardner et al (2005). Loneliness was not associated with processing of happy faces or social positive scenes as indicated in the SMS model. That model suggests that lonely adults monitor the social environment for positive and negative social cues in an attempt to regain social connections, but the findings of the studies are not consistent with this proposal.

The current set of studies (2 to 5) controlled for social anxiety and depression in the analyses. Controlling for these related constructs are important because they share features with loneliness and cognitive biases. However, the practical implications should be based on the findings for loneliness only because the variance due to social anxiety and depression cannot be removed from people who are lonely in everyday life.

Practical implications of the current set of studies

The findings suggest that lonely adults are hypervigilant to social threats that are linked to angry faces (studies 3 and 4) and social rejection (study 5). Thus, interventions for lonely people should focus on addressing the cognitive bias and support lonely adults to re-frame situations that they view as threatening as suggested elsewhere. Also, attempting to provide skills to lonely adults on how to relocate their attention from socially threatening information is important because this difficulty in disengagement could be involved in the maintenance of loneliness (Qualter et al, 2013b). The findings also indicate that cognitive-behavioural strategies would best support those that are high on loneliness because those individuals were found to have the most difficulty in disengaging from social threat and this group should be the primary focus for any interventions proposed. In addition, interventions that teach lonely people skills to relocate attention from social threats and monitor the social environment for positive social cues may be effective, as proposed by Gardner et al (2005) in their model. But, research is needed to examine whether the cognitive biases cause behavioural deficiencies, so more effective interventions can be developed.

Direction for further study

Based on the findings of studies 1 and 5, the most consistent evidence found using eye-tracker methodology that requires further examination is the notion that lonely adults are hypervigilant to social threats linked to issues of social rejection/social exclusion and not to issues of threat in general. The next step in the current research was to examine how these social threats linked to social rejection are detected and processed in the brain and whether these differ between lonely and non-lonely participants.

Chapter 5: Neuroimaging Techniques

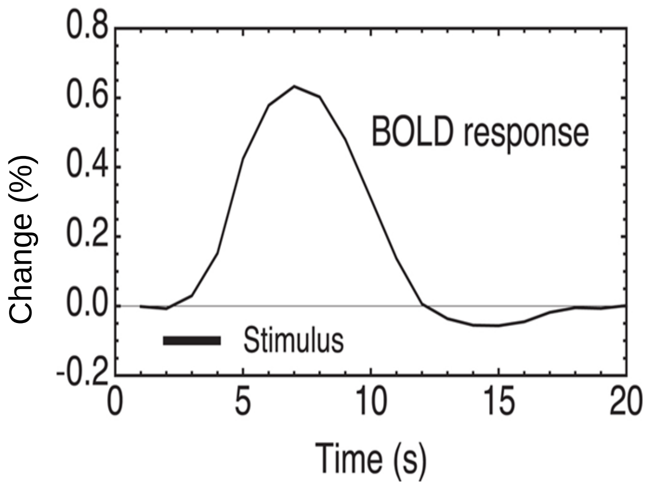
Various imaging techniques have been developed in the last hundred years to examine how the brain functions and to provide useful information on which brain regions are activated and when. This review chapter outlines the two main neuroimaging techniques used by neuroscientists to understand information processing in the brain during cognitive tasks, a domain referred to as cognitive neuroscience. The two techniques (functional magnetic resonance imaging, fMRI and electroencephalography, EEG) discussed in this chapter are directly relevant to the empirical study (chapter 6) that follows. Both these techniques assess changes in brain function during cognitive tasks by measuring neural activity or changes associated with neuronal activity. EEG directly measures neuronal activity by attaching electrodes or sensors to the surface of the scalp, whilst fMRI indirectly assesses neuronal activity by measuring the oxyhaemoglobin used by neurons. The two neuroimaging techniques are discussed below in detail. The latter section of this chapter outlines the current research in neuroimaging for loneliness followed by a rationale for examining the spatial and temporal domains of hypervigilance to social threat using EEG methodology.

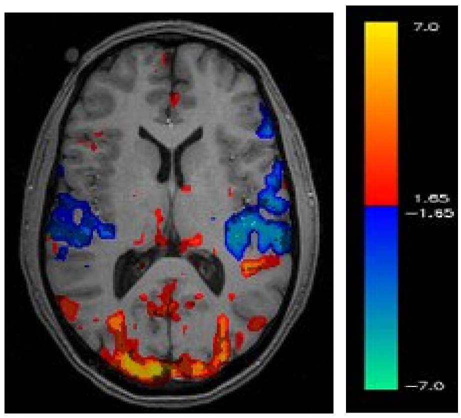
Functional magnetic resonance imaging (fMRI)

FMRI is an imaging technique which provides information about the function of the brain when participants perform a cognitive task in a strong magnetic field (provided by an MRI scanner). FMRI assesses the electrical activity of neurons by indirectly measuring a physiological marker associated with neuronal activity. The most commonly used measure is the BOLD (blood oxygen level-dependent) signal with the premise that oxygen supplies the energy for neuronal activity and haemoglobin is the molecule that carries this oxygen in red blood cells. The BOLD signal measures the ratio of oxyhaemoglobin (i.e. haemoglobin molecule containing oxygen) and deoxyhaemoglobin (haemoglobin molecule without oxygen). When neuronal activity increases, there is a greater demand for oxygen. Therefore, oxyhaemoglobin is carried to those brain areas resulting in lower levels of deoxyhaemoglobin in the blood. Oxyhaemoglobin and deoxyhaemoglobin differ in their magnetic properties, and alter the magnetic susceptibility of the blood.

The fMRI signal detects these contrast changes and a stronger signal means more oxyhaemoglobin in the blood is present in that area. Figure 5.1 (left) illustrates the BOLD signal which peaks at around 6 seconds. Due to this delay in response the precise timings of neural events are not easily deduced (I.e. lacks temporal resolution). The main principle of the BOLD approach is that increase brain/neural activation involves an increase blood flow and more oxygen in the blood results in brighter levels on images. Figure 5.1 (right) shows an activation map). Image data is processed every 1 to 3 seconds based on the BOLD signal to provide information about brain function (Buxton, 2013; Song, Huettel & McCarthy, 2006).

Figure 5.1: Left: representation of the BOLD curve (Buxton, 2013: page 49). Right: fMRI activation map with corresponding colour scale i.e. greater activation = yellow, reduced activation = blue (Devlin, 2007)





Analyses of fMRI data

FMRI data is primarily analysed in the spatial domain providing information of how brain structures are related to function. Initially, the subtraction logic is used on neuroimaging brain activation data because the signal strength varies on a number of factors. The subtraction logic is when researchers compare two conditions which only differ by one factor (e.g. different type of picture stimuli) and subtract out all the activation apart from the activation of interest (Amaro Jr & Barker, 2006; Culham, 2006; Friston, 1997). The subtraction method is used alongside other approaches described below.

One of the standard ways to examine fMRI data is using a voxelwise approach. A voxel is equivalent to a pixel on a computer screen and is a representation of an image in cubes (see Figure 5.2 left). The approach examines data on a voxel-by-voxel basis on whole brain scans (comparing each voxel to every other voxel) and then statistically evaluates differences in specific brain regions based on activation levels (Gregory, 2011). The voxelwise approach is useful because it allows the examination of the whole brain without prior assumption on activation of specific brain regions. However, a large number of voxels (i.e. tens of thousands) are acquired in an fMRI image, so multiple statistical comparisons are made which require the use of adjusted p values (Logan & Rowe, 2004). Alternate methods are used that base significance levels on clusters of activated voxels (Friston et al, 1994).

For these approaches, data are transformed into a standard space whereby different brains are averaged irrespective of size. The main system of standardising brain space is the Talairach atlas (Talairach & Tournoux, 1988). More recently, this system has been warped into MNI space (Montreal Neurological Institute space; Evans et al., 1993). MNI space is argued to be a more representative system because it uses the average of many human brains (N = 305) as a standardised template, unlike the Talairach system that only uses a single brain. The two systems are consistently used in neuroimaging research and provide x, y, z co-ordinates that directly map onto templates of brain regions that are pre-determined. The co-ordinates represent the distance from the identifiable brain region known as the anterior commissure which is a bundle of fibres connecting the two hemispheres. As shown in Figure 5.2 (right) X represents left/right, Y represents anterior/posterior (front/back), Z represents dorsal/ventral (top/bottom) region. For example xyz co-ordinates -7, 54, 2 are mapped onto Brodmann area 10 and the brain region anterior prefrontal cortex.

Figure 5.2: Left: representation of a voxel (like a pixel on a computer screen) on an fMRI brain image (from Phillip & Ilan, 2009). Right: illustration of the brain showing the xyz co-ordinates (from Rorden, 2002).

FMRI is one of the neuroimaging techniques used in cognitive neuroscience. The major facets of fMRI are outlined in table 5.1 and these are compared to the EEG neuroimaging technique.

Table 5.1 comprises of two neuroimaging techniques (fMRI vs EEG)

Parameter	fMRI	EEG
Practicality of use	Excellent	Excellent
Spatial resolution (location)	Good ~1 millimetre range	Poor/undefined
Temporal resolution (time)	Poor ~1 second	Excellent ~1 milliseconds
Measure of brain activity	Indirect	Direct
Cost	Expensive	Inexpensive

Electroencephalography (EEG)

EEG is a technique that measures direct neuronal activity from groups of neurons in the brain and provides information on the time-course of neural events that are consistent with changing behaviour and/or information processing (refer to table 5.1 for contrasting parameters with fMRI). EEG measures electrical activity of action potentials and post-synaptic potentials. Action potentials rapidly travel from the cell body of neurons to the pre-synaptic regions, which cause neurotransmitters to be released in the synapse. Post-synaptic potentials are longer lasting and occur when the neurotransmitters bind to receptors on the outside of post-synaptic cells. This binding leads to an influx of ions through the opening and closing of the ion channels and causes a measurable voltage change across the cell membrane (Handy, 2005). Specifically, scalp EEG is thought to measure the summation of excitatory and inhibitory post-synaptic dendritic potentials of cortical pyramidal cells that yield a dipolar field. A dipole within a dipolar field consists of a positive and negative electrical charge separated by a small distance that is generated by positive ions flowing into the post-synaptic neuron and negative ions passing into other areas of the neuron. Dipoles from individual neurons are too small to be measured by scalp electrodes. This means dipoles from many neurons summate at the same time and dipoles from individual neurons have to be similarly orientated to be recordable at the scalp by the EEG (Luck, 2005).

However, identifying the source of the electrical signal is problematic using EEG. This is commonly referred to as the inverse problem in which the location and orientation of the dipoles observed on the scalp cannot be provided by only the observed voltage distributions (Handy, 2005). This is because there are different sets of dipoles and sources that may produce the same pattern of voltage distribution. Researchers have developed techniques to overcome this drawback of EEG by using mathematical modelling and creating linear inverse solutions (Luck, 2005). These methods are discussed later in the chapter. Even with this limitation, EEG is widely used for research purposes to examine the timings of neuronal events during cognitive tasks because of the excellent temporal resolution (refer to table 5.1). A brief background to EEG method is given below.

EEG systems

There are two different types of EEG systems available: net systems and gel filled systems. Net systems or high-density electrode arrays typically include 128 or 256 electrodes which are arranged in a net, soaked in gel containing water and placed on the participants scalp. In contrast, traditional gel-filled systems typically include 32 or 64 electrodes, which are placed on the participants scalp using an electrode cap and gel is filled into individual electrodes. Each system is associated with pros and cons, but both of these systems are commonly used in EEG research. The high density electrode arrays are thought to have a few advantages over traditional methods because they cover most of the scalp with electrodes (i.e. more spatially distributed) and they process electrical activity from a shorter distance (less than 3 cm) around each electrode making EEG analysis more objective (Srinivasan, 2005).

Electrode placement

Electrodes are placed on the head covering most of the scalp in line with the 10-20 System put forward by Jasper in 1958. The naming conventions of these electrodes are typically arranged as a letter and number (e.g. F2, P7). The first letter corresponds with the region of the brain site that the electrode is placed on (F = frontal region, C = central region, T = temporal region, P = parietal region and O = occipital region). The following naming convention corresponds to a number; odd numbers are specified to the left side of the head and even numbers correspond to the right side of the head. These numbers also denote the distance from the middle of the head, so F3 electrode is closer to the midline then the F7 electrode. However, the 10-5 naming system proposed by Oostenveld and Praamstra (2001) is an extension of the traditional 10-20 system to accommodate for the increased number of electrodes used in high density arrays (see Figure 5.3). In addition, reference electrodes are reference points in which all other electrode activity is processed and normalised from. These electrodes are placed on relatively inactive brain sites from which the least amount of EEG activity is present. The most common reference electrodes used in research are the linked-ear reference or Cz vertex (middle distance from the left/right and front/back of the head) reference but the choice of reference electrodes varies across researchers.

Figure 5.3: Electrode placement of the scalp based on the 10-5 system for high density electrode arrays from Oostenveld and Praamstra (2001, page 716)

[redacted]

From EEG to ERPs

Raw EEG data has many formidable issues and cleaning the data is a crucial step to get a clean EEG signal in cognitive experiments. Many steps are involved in pre-processing of raw data and standard procedures are used to address these issues. Artefacts are reduced based on biological and non-biological parameters. Biological artefacts are eye movements/eye blinks and muscular movements, whilst non-biological artefacts are those that include external electrical noise and noise from scalp recording electrodes (Davidson, Jackson & Larson, 2000).

Raw EEG waves are characterised by differences in their frequency and amplitude in certain behavioural states such as alertness or relaxing. The EEG consists of five different frequency bands measurable in hertz (Hz); delta (0-4

Hz), theta (5-7 Hz), alpha (8-12 Hz), beta (13-30 Hz) and gamma (36-44 Hz) range. However, this information is limited for researchers who want to understand the time course of neural events in relation to a specific event in cognitive tasks. Therefore, data are extracted from EEG data in the form of event-related potentials (ERPs).

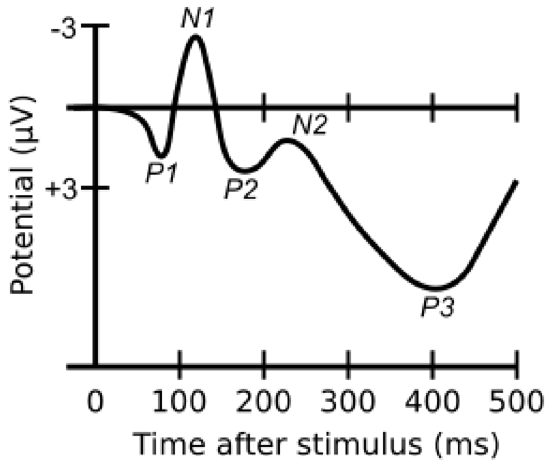
ERPs are signal-averages taken from the raw EEG data that are in response to a specific event or stimulus (i.e. time-locked to events) (Blackwood & Muir, 1990). Due to the nature of ERPs and level of noise in the signal (Signal to Noise Ratio; SNR), a sufficient number of trials (> 20) are needed per experimental condition in tasks to form averages and pinpoint specific event activity. ERP data can be analysed and quantified using three overlapping categories based on the nature of data the researcher is interested in. These are temporal (time), spatial (location) and spatio-temporal (location and time) analyses and these are considered in more detail below.

Analyses of ERP data

Temporal analyses

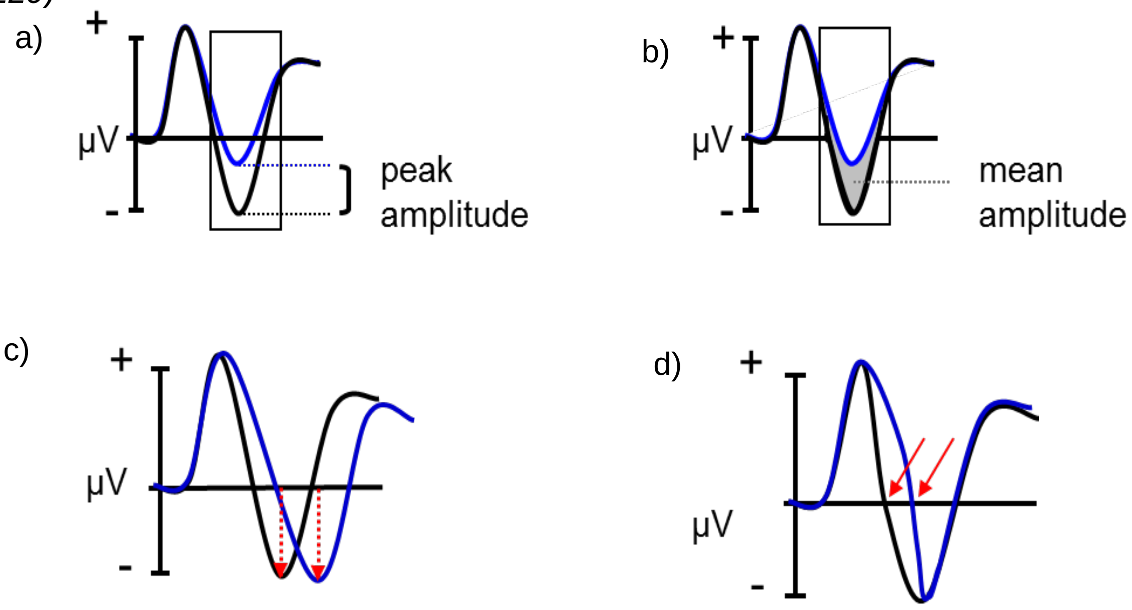
The traditional and standard way of analysing ERP data is in the temporal dimension. This is when ERP waveforms measured from individual electrode sites are examined as a function of time across different experimental conditions. The main parameters used in this analysis are latency, polarity and amplitude of specific ERP components observed in the ERP waveform. ERP components are voltage changes across individual electrode sites in the waveform. ERP components are labelled based on their polarity (P = positive, N = negative) and their position or latency within the waveform. These labels map onto observed timings and spatial distribution. For instance, the N400 component peaks at approximately 400 milliseconds after stimulus onset and is observed at the central-parietal electrode sites. Moreover, ERP components are divided into early and late components. Early components (i.e. P1) observed within the first 100 ms after stimulus onset are referred to as sensory because they depend on the physical properties of the stimulus, while later components (i.e. P300, N400) are referred to as cognitive because they examine information processing (Sur & Sinha, 2009). Figure 5.4 shows the early (less than 400ms post stimulus onset) major components observed in the waveform that are characterised on their amplitude and latency in visual tasks.

Figure 5.4: Representation of visual ERP waveform with typical early ERP components (e.g. P1) labelled (Luck, 2005: page 35)



The amplitude (measured in microvolts) of components is measured in two ways. The first method is the peak amplitude measure that involves finding maximum amplitude differences for each waveform in a specified time window (see Figure 5.5 a). The second method is the mean amplitude measure that calculates the mean voltage across each waveform in a specified time window (see Figure 5.5 b). Similarly, ERP latencies (measured in ms) are measurable parameters. The peak latency measure identifies the specific time point of the peak amplitude (see Figure 5.5 c). The onset latency is the measure of what time the ERP component began (see Figure 5.5 d) (Handy, 2005). However, the temporal analysis only gives information about the timing of neuronal changes in milliseconds and does not provide detailed information on the spatial locations of the electrical activity.

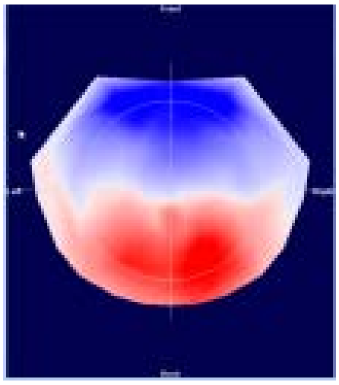
Figure 5.5: Illustration of temporal measures a) peak amplitude, b) mean amplitude, c) peak latency, d) onset latency (adapted from Luck, 2005; page 229)



Spatial visualisation and analyses

Another way to visualise ERP data is in the spatial dimension. In this approach, voltage changes across all electrodes' sites placed on the scalp are analysed in a specific time window by topographic mapping. Scalp maps showing voltage changes across all electrode sites are then compared between experimental conditions using subtraction logic. Typically, different colours on maps highlight the voltage changes and different colour intensities highlight the level of voltage change (see Figure 5.6). Also, topographic mapping includes a description of global strength which is known as global field power (GFP). GFP is the measure of potential at a given time and informs the researchers on how strong the potential being recorded is, but does not provide information on how this potential is distributed across the electrodes. Commonly, high GFP is associated with stable potential field whilst low GFP is related to changes in potential field. GFP is computed based on the standard deviation of all electrodes at a given time point using an equation. GFP is consistently used in spatial analysis as a measure of strength in topographic mapping (Koenig & Gianotti, 2009; Murray, Brunet & Michel, 2008).

Figure 5.6: Scalp map of voltage change in the spatial dimension for the time period 288-356ms. The colour red shows an increased voltage difference across posterior electrode sites, while blue shows a decreased voltage difference across anterior electrode sites. Greater colour intensity shows larger the voltage difference while less colour intensity shows smaller voltage differences (adapted from Michel et al, 2009: page 119).



ERP data can also be analysed in the spatial dimension using source localisation techniques. This technique estimates the brain sources of EEG and provides information on where in the brain the activity is coming from. Brain source localisation is directly implemented onto ERP components and/or brain microstates (see below). A class of linear distributed solutions to the inverse problem have been developed (e.g. weighted minimum-norm estimates: wMNE), low resolution brain electromagnetic tomography: LORETA). These approaches use mathematical inferences to estimate brain source localisation and the strength of the source within a 3-dimensional solution space, without making assumptions about the number of active brain sources (Michel et al, 2004; Pizzagalli, 2007). LORETA and wMNE either use the spherical head model that is registered to the Talairach brain atlas or MNI space and provides xyz co-ordinates. However, this analysis only provides information spatially and does not examine the timing of neuronal change in cognitive tasks.

Spatio-temporal analyses

The final approach (and the approach taken in the next empirical chapter) to examine ERP data is in the spatio-temporal domain. This examines how topographic maps change across time, thus providing information on both the voltage changes on the scalp and the timing associated with these changes (i.e. amplitude and latency). One such approach that compliments traditional ERP analyses is the microstate approach developed by Lehmann in the 1980s (Lehmann & Skrandies, 1980). This approach looks at activity across the entire scalp (brain topographies) and redefines ERP components as map topographies, instead of looking at peaks for certain electrode sites at a given time. It examines data in the spatial domain first and then in the temporal domain (Brunet, Murray & Michel, 2011; Murray et al, 2008; Pascual-Marqui, Michel & Lehmann, 1995). This approach is discussed in more detail below.

The microstate approach proposes that stimulus presentation evokes a sequence of brain patterns which reflect discrete information processing operations. The sequence of information processing includes stable brain activities called microstates with each microstate related to a different step in processing. For example, when a face is presented visually the sequence of microstates is related to the different steps of face processing. Common brain structures may give rise to different microstates as well as similar microstates appearing in different experimental conditions (Ortigue, Patel & Bianchi-Demicheli, 2009). A microstate is characterised by spatial domains: electrical maxima (positive, negative), orientation (anterior, posterior), location (left, right hemisphere), and temporal domains; latency (onset, offset) and duration (Lehmann, 1987). Brain microstates remain stable for some time before changing into another microstate which also remains stable for some time, but they do not occur at regular intervals. Microstates are then compared and evaluated across different experimental conditions or between groups using statistical analyses (i.e. ANOVAs).

Microstates are identified using data clustering techniques (e.g. K-means cluster) on grouped-averaged ERP data for each condition and they provide specific information on the duration (start, end) and nature of each brain microstate. Initially, the data is segmented into multiple microstates at random using an algorithm and a template map showing the topography is created within a timeframe. This template map is used to recalculate the data into clusters based on strong correlations within each timeframe until a set of stable microstates are formed. The clustering approach is repeated many times because the segmentation number is derived at random.

Recently, the K-cluster analysis used to micro-segment brain microstates has been criticised. Firstly, the number of clusters used in micro-segmentation is specified at random by the researcher, which leads to confirmatory and generalisability issues. Secondly, topography mapping of the cluster formation with the template map occurs on similarity features that are not based on time, whilst information processing operations (i.e. microstates) vary as a function of time. Thirdly, cluster analysis does not differentiate between transition and stable microstates. Stable microstates may not necessarily change directly from one to another, but transition states may occur and the inclusion of these transition states in stable microstates make the identification of brain structures in source localisation more difficult. Finally, cluster analysis does not provide any information on how microstates differ across individual participants because k-clusters are performed on grouped average ERP data (S. Cacioppo, Weiss, Runesha & Cacioppo, 2014). The drawbacks of this technique have been overcome using a new method described below.

S. Cacioppo et al (2014), in a recent theoretical paper, propose a new quantitative method for micro-segmentation of ERP data into stable and transition ERP microstates providing information on which and when brain regions are activated by a task. This newly developed algorithm addresses the four limitations of the K-cluster analyses outlined above. The microstate ERP data described in the next empirical chapter is derived using the Chicago Electro-Neuroimaging Analytics (CENA) suite (S. Cacioppo et al, 2014). ERP data is divided into a baseline state, transition states, and stable brain microstates using a root mean square error algorithm, without the need to specify the initial number of microstates needed for segmentation. This provides information on the onset and duration of each microstate identified. Then the GFP of each microstate is computed using the measure of standard deviation of all electrodes at a given time. These analyses are applied on high density ERP grand averages. A similarity metric is used to determine whether template maps of microstates differ to the microstate before in patterns of activity, GFP or both. The CENA approach to micro-segmentation of ERP data has been validated by the authors in a basic visual paradigm task yielding results that are comparable with previous literature on the task (S. Cacioppo et al, 2014).

Current EEG/ERP study

The EEG/ERP study described in the next empirical chapter uses the suite of quantitative methods (CENA) put forward by Cacioppo et al (2014) to identify stable microstates in the brain. This provides information on duration, onset, offset, and mean GFP of each microstate identified. Furthermore, each identified microstate is mapped on to brain structures by using brain source localisation method wMNE. This provides MNI co-ordinates (xyz) that may be used for the identification of specific brain structures. The graphical data presented in the next chapter is consistent with the data that can be obtained from an fMRI study. Therefore, the data indicates which brain areas are activated (spatial) by the task and at what time point (temporal).

Current research on neuroimaging for loneliness

The current research in the loneliness literature using neuroimaging techniques is very sparse with only three published studies examining brain structures and functioning of lonely people. Two studies identified specific brain structures that were related to loneliness using voxel-based morphometry in which whole brain images were acquired during a MRI scan and specialised software correlates the density of grey matter with the UCLA loneliness measure. Kunai et al (2012) found that lonely people had reduced grey matter in the left posterior superior temporal sulcus (pSTS; a brain area that has been implicated in basic social perception skills and processing of social information). Kong et al (2014) found that lonely Chinese adults had more grey matter volume in the left dorsolateral prefrontal cortex (DLPFC), a brain area that has been implicated in emotional regulation, suggesting that lonely people may be ineffective in regulating their emotions. However, these studies are speculative and certain brain regions may not be directly involved in the complex cognitive aspects associated with feelings of loneliness.

Research also shows that loneliness is reflected in the way the brain processes visually presented information using neuroimaging techniques. During an fMRI study, Cacioppo et al (2009) showed participants pictures chosen from the IAPS database that varied in their emotional (pleasant/unpleasant) and social (non-social/social) content. The social pictures included in the study were not chosen to show social relationships or social interactions, but were included to examine loneliness and basic social perception. The pictures used may not be reflective of socially threatening pictures to which lonely people are hypervigilant. The authors conducted two contrasts (pleasant social minus pleasant non-social pictures and unpleasant social minus unpleasant non-social pictures) to investigate whether loneliness was associated with brain activation in the contrasting conditions when viewing pictures that varied on their emotional and social content. Findings for the pleasant picture contrast indicated that lonely individuals showed less activation of the ventral striatum (a part of the nucleus accumbens involved in reward circuitry) when viewing pictures of people compared to objects, whereas non-lonely individuals showed greater activation in the ventral striatum when viewing pictures of people versus objects. This suggests that lonely people are less rewarded by social stimuli than non-lonely people. Findings for the unpleasant picture contrast indicate that lonely individuals showed greater activation in the visual cortex to pictures of people then objects, whereas non-lonely individuals showed greater activation in the tempero-parietal junction to pictures of people than objects. This suggests that lonely people showed greater attention to negative social pictures. To date, this is the only study to examine functional brain activity in lonely people which found different brain activations when viewing unpleasant social pictures. This finding is consistent with the loneliness literature which suggests that lonely people are on heightened alert for negative social information.

Similar fMRI studies to the study mentioned above have identified specific brain regions when viewing social compared to non-social pictures in experimentally socially excluded participants. Powers, Wagner, Norris and Heatherton (2013) found that socially excluded individuals did not recruit the dorsomedial prefrontal cortex (dmPFC; a brain region involved in mentalising) in viewing social compared to non-social pictures, while socially included participants showed greater activity in dmPFC when viewing social pictures compared to non-social pictures. A related literature on the neural correlates of social exclusion suggests that the social pain of rejection overlaps with the pain matrix involved in physical pain (Eisenberger, 2012). Eisenberger, Lieberman and Williams (2003) reported that social rejection increased activity in the dorsal anterior cingulate cortex (dACC), insula and right ventral prefrontal cortex regions; findings that mirror the neural correlates associated with physical pain.

The latter set of studies described above, need to be interpreted with caution in relation to loneliness. Experiencing social exclusion through paradigms such as the cyber-ball task (online ball tossing game where participants are led to believe that they are playing with two or three players, when in fact there are playing against the computer manipulated by the researcher) or modified feedback on inclusion/exclusion is not the same as feeling loneliness. Loneliness is a subjective experience related to the dissatisfaction with current social relationships and is not the same as social exclusion. In addition, a review of functional imaging of social rejection studies using the cyber-ball paradigm failed to find evidence that social rejection shares the same pain matrix associated with physical pain (Cacioppo et al, 2013). The authors suggest that the cyber-ball paradigm may not activate real social pain because the social rejection is initiated by strangers and not by a person that is significant to the participants' life. This indicates that social exclusion paradigms may not reflect the social pain associated with loneliness.

Rationale for current EEG study

Based on the findings from study 1 (chapter 3) and study 5 (chapter 4), lonely people appear to show visual attention biases to socially threatening stimuli linked to social rejection/social exclusion. Different patterns of visual attention were found in both studies: lonely adults showed a hypervigilance-avoidance response to real-life footage of social threat (study 1), but they showed disengagement difficulties to static images of social threat (study 5). An important question that is missing from the loneliness literature is how lonely people process social threat information. The next empirical chapter addresses this question and describes an EEG/ERP study that examines the spatio-temporal dynamics of hypervigilance to social threat linked to social rejection in loneliness.

Chapter 6: Study 6 - Loneliness and Implicit Attention to Social Threat: A high performance electrical neuroimaging study

Abstract

Prior research has suggested that loneliness is associated with an implicit hypervigilance to social threats. Little is known, however, about the temporal dynamics for social threat (vs. non-social threat) in the brains of lonely individuals. The study reported here used high-density electrical neuroimaging and a behavioural task including social threat and non-social threat (and neutral) IAPS pictures to investigate the brain dynamics of implicit processing for social threat (vs. non-social threat) stimuli in lonely individuals compared to non-lonely individuals (N = 19). The present study provides evidence that social threat images are differentiated from non-social threat stimuli more quickly in the lonely (~116 ms after stimulus onset) than non-lonely (~252 ms after stimulus onset) brains. This speed of threat processing within brain areas involved in attention and self-representation is consistent with the evolutionary model of loneliness.

Introduction

Loneliness (the subjective perception of feeling socially isolated) can happen to any of us. Paradoxically, feeling lonely not only increases the *explicit* desire to connect or re-connect with others, but it also produces an *implicit* hypervigilance for social threats (cf. Cacioppo & Hawkley, 2009; Cacioppo et al., 2014), which is likely to reflect an adaptation of the predator evasion defense, previously documented in socially isolated rodents (Hofer, 2009; Kaushal, Nair, Gozal, & Ramesh, 2012; Cacioppo & Hawkley, 2009). This evolutionary theory of loneliness (Cacioppo & Hawkley, 2009) suggests that loneliness leads to increased surveillance of the social world, which produces cognitive biases with an unwitting focus on self-preservation.

Evidence from behavioural and functional magnetic resonance imaging (fMRI) studies supports the notion that loneliness increases attention to negative social stimuli. For instance, Cacioppo et al. (2009) identified a specific brain signature associated with perceived social isolation in a brain imaging study in which participants were asked to view pictures showing social/non-social or pleasant/unpleasant scenes from the International Affective Picture

System (IAPS). Results showed that participants who scored higher on the continuum of loneliness showed less activation of the ventral striatum (a brain area activated during rewarding experiences) to pleasant social pictures (people) than non-social pictures (objects); participants who scored lower on the continuum of loneliness showed greater activation to pleasant social than non-social pictures. Additionally, participants scoring higher on the continuum of loneliness showed greater activation of the visual cortex in response to unpleasant social than non-social pictures. This is consistent with the notion that the lonelier a person feels, the more attentive they are to the social context in the presence of negative stimuli or threats. Whilst participants scoring lower on the continuum of loneliness showed greater activation of the temporal parietal junction (TPJ) in response to unpleasant social than non-social pictures. This suggests that lonely individuals are more focused on themselves and on self-preservation in negative social contexts. These neuroimaging data parallel the behavioral findings from a social Stroop task indicating that loneliness predicts the extent to which a stimulus elicits preattentinal processing (Egidi et al, 2008). It appears, then, that perceiving oneself to be on the social periphery makes people feel unsafe, which sets off implicit hypervigilance for social threat in the environment.

The finding that loneliness is associated with an increase in attention to negative social information mirrors findings from studies 1 and 5, which shows that lonely people show greater visual attention to social threats linked to social rejection or social exclusion. Specifically, study 1 (chapter 3) found that lonely young adults initially fixed their attention on social rejection cues of real-life video footage, but then avoided them. In addition, study 5 (chapter 4) found that lonely adults were unable to re-direct their attention from static pictures depicting social rejection. Taken together, the behavioural and neuroimaging research suggests that lonely people show automatic (non-conscious) attentional biases for social threats such as social rejection. Little is known, however, about the spatio-temporal dynamic of this automatic hypervigilance to social threat in the brain as a function of loneliness.

The present study

The goal of the present study was to use high-density electrical neuroimaging to determine the spatio-temporal dynamics of automatic social threat detection and to examine differences in electrical brain activity of lonely and non-lonely individuals whilst viewing pictures that varied on social/non-social and threat/non-threat content. Specifically, the focus of the study was to examine differences whilst viewing threat pictures that varied on social/non-social content. The study hypothesised that social threat in contrast to non-social threat images would elicit greater visual cortical activation in lonely than non-lonely individuals, whereas social threat compared to non-social threat images would subsequently elicit greater activation in the posterior temporal regions (e.g., TPJ) in non-lonely than lonely individuals. Based on a neurobiological model developed by Cacioppo, Cacioppo, Capitanio, and Cole (2015) in a review of relevant animal research, this study predicted that regions including the anterior prefrontal cortex, dorsolateral prefrontal cortex, and amygdala/extended amygdala (i.e., bed nucleus of the stria terminalis, BNST) would be among the areas involved in orchestrating the differences in response to social threat in contrast to non-social threat.

Methods

Design

A 2 x 2 mixed design was used in the behavioural component of this study. The level of loneliness of the participants (lonely, non-lonely) was the independent variable, and the subjective valence ratings (positive/negative) and reaction time (ms) for the type of stimuli (social/non-social) and nature of stimuli (threat/non-threat) were the dependent variables. A 2 x 2 mixed design was used in the EEG component of this study. The level of loneliness (lonely, non-lonely) was the independent variable and the spatial and temporal domain of the neural responses (microstates) to the social threat and non-social threat pictures were the dependent variables.

Participants

A total of twenty-seven volunteers (15 females, 12 males) participated in the present study. All were right-handed (Edinburgh Handedness Inventory, Oldfield, 1971), English speakers, had normal or corrected to-normal visual acuity, and were students at the University of Chicago. Data from five volunteers were excluded due to artifacts in EEG data, and a further three participants' data were excluded due to consistently high reaction time results in the behavioural task. Thus, EEG data from 19 (10 females, 9 males) volunteers were analysed. Mean age of the final set of participants was 24.05 years (range 18 to 28 years for females; 20 to 44 years for males). The Ethical Committee of the University of Chicago, Illinois, approved the study. Prior to participation, volunteers provided oral informed consent. All participants were paid $15 per hour for their participation in the study.

Self-report questionnaires

To assess participants' level of loneliness, all participants completed the R-UCLA Loneliness Scale (Version 3, Russell, 1996), which includes 20 items measuring general loneliness and degree of satisfaction with one's social relationships (e.g. "How often do you feel that there is no one you can turn to?") out of four possible options (Never, Rarely, Sometimes, Often). Higher scores represent higher levels of loneliness. The loneliness scores of this sample ranged from 23-60. Using the mean loneliness score of 42.26; 10 of the participants were grouped as lonely, while 9 of them were grouped as non-lonely. The scale exhibited excellent internal consistency, $\alpha = .95$.

Participants also completed the Interaction Anxiousness Scale (IAS; Leary, 1983b; Leary & Knowalski, 1993) to assess levels of social anxiety. The IAS comprises 15 questions; participants were asked to rate each statement on how characteristic it is of them using a 5-point scale (1 = not at all to 5 = extremely). Higher scores indicate higher levels of social anxiety. The scale exhibited good internal consistency, $\alpha = .84$. In addition, participants completed The Center for Epidemiologic Studies Depression Scale (CES-D: Radloff, 1977) to assess depressive symptomology. The scale includes 20 items requiring participants to indicate how often they felt the way described in the past week from four possible options (rarely or none of the time; some or a little of the time; occasionally or a moderate amount of time; most or all of a time), but in the current study the item 'I felt lonely' was removed from the total score to avoid any such variance overlap between the two constructs. Higher scores indicate higher levels of depressive symptoms. The scale exhibited excellent internal consistency, $\alpha = .91$.

Materials

Stimuli were 28 pictures that varied in social (social, non-social) and threat (threat, non-threat) content (*N* = 7 pictures per category). These pictures were selected from the IAPS database (Lang, Bradley & Cuthbert, 2008) and a subset from study 5 (chapter 4). Example stimuli are as follows: a crying boy and a child being rejected by his peers as social threat pictures; a series of snake pictures as non-social threat pictures; people cooking together and people walking in a crowd as social non-threat pictures; a landscape and a book as non-social non-threat pictures. The social threat pictures were chosen to present instances of social rejection by others or sadness and non-social threat pictures showed a biological threat that produces a fear response in the majority of individuals; the social non-threat pictures were chosen to present social interactions, while non-social non-threat pictures were pictures of objects and scenery that have been shown to produce neutral ratings. Refer to Appendix B for stimuli details used in study 5).

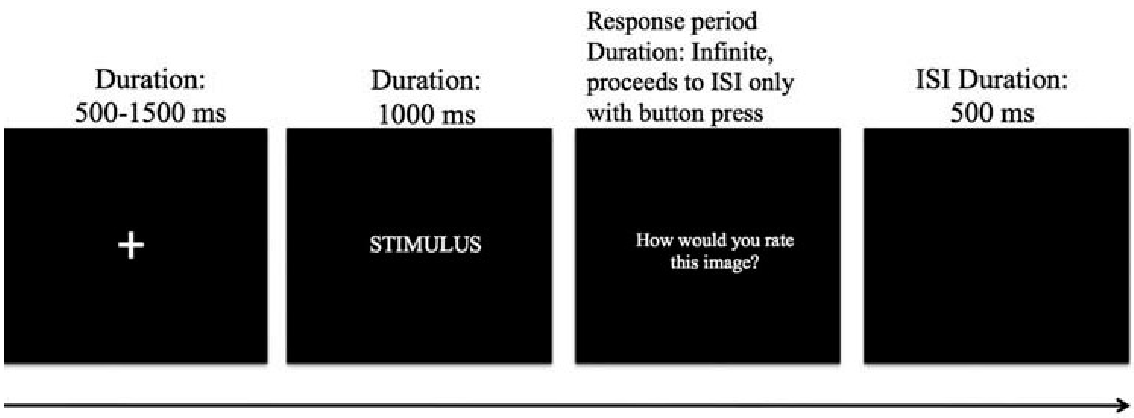
A sample of 105 participants (*M* = 33, *F* = 72, age range = 18 to 55 years), comprised of individuals who did not participate in the EEG study, pre-rated the pictures used in the current EEG study, on a scale of 1 to 9 (1 = negative, 9 = positive) using a similar approach taken by Lang et al (2008) when standardizing the IAPS pictures. Mean valence ratings for social threat (*M* = 2.33, *SD* = 0.14) and non-social threat picture categories (*M* = 4.24, *SD* = 0.43) were rated as more unpleasant than social non-threat (*M* = 5.16, *SD* = 0.55) and non-social non-threat picture categories (*M* = 6.28, *SD* = 0.47). The participants also completed the UCLA Loneliness scale. Based on their scores, two groups were formed. The lonely group included participants who scored 60 or above on the UCLA (26 participants); the remaining participants were included in the non-lonely group. Mean scores for valence, arousal and dominance domains for social threat and non-social threat pictures were computed for each participant. A set of independent samples t-test revealed no significant differences ($p > .05$) between lonely and non-lonely groups on ratings for valence, arousal and dominance for both picture categories (social threat and non-social threat). This suggests that lonely people may show an implicit hypervigilance to social threats on a non-conscious level.

Procedure

Participants were instructed to gaze at the center of the screen, and were asked to view each picture. They were asked to make a categorical judgment regarding the valence of each picture during the response slide (“How would you rate this image?”) by pressing one of four keys on a touch pad on a scale of -2 and -1 as unpleasant, and +1 and +2 as pleasant. They were asked to respond as quickly as possible.

Participants viewed a total of 7 blocks of pictures with each block containing the 28 pictures. Each picture from each category was presented once in a block. The order of the blocks was randomized for each participant, but the order of the pictures within the block was pre-determined with no more than three consecutive trials of the same picture-type presented. Prior to each trial, participants viewed a white fixation cross on a black background that varied between 500 -1500 ms. Each picture was presented in colour for 1000 ms, followed by a response slide that required a button press to move onto the inter-stimulus interval (ISI) for 500 ms (Figure 6.1). Reaction times and valence ratings were recorded from a PC computer using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

Figure 6.1: Trial structure of the experimental design shown to participants in the EEG study



Electrophysiological Recordings

Continuous electroencephalogram (EEG) was recorded from 128 AgCl carbon-fiber coated electrodes using an Electric Geodesic Sensor Net® (GSN300; Electrical Geodesic Inc., Oregon; http://www.egi.com/), where EEG electrodes are arrayed in a dense and regular distribution across the head surface with an inter-sensor distance of approximately 3cm. The EEG was digitized at 250 Hz (corresponding to a sample bin of 4 ms), band-width at 0.01–200 Hz, with the vertex electrode (Cz) serving as an on-line recording reference; impedances were kept below 100kΩ. Participants were seated in a comfortable chair about 110 cm away from a PC computer screen, with pictures presented in the center of that screen.

Data analyses

Behavioural pre-processing

Reaction time data were screened and any outliers were removed based on each participant's trial-by-trial data. A trial was removed if it differed by 3 standard deviations above or below the participant's mean (15.58% observations were rejected). On a participant level, following data screening, data for three participants were removed from behavioural and EEG data because they had consistently high reaction times across all picture categories.

Initially, to examine the relationship between loneliness and valence ratings, and reaction times to social threat, two separate 2 (level of loneliness: lonely, non-lonely) x 2 (type of stimuli: social, non-social) x 2 (nature of stimuli: threat, non-threat) ANOVAs were conducted. The first looked at reaction time and, the second, looked at valence ratings in response to all stimuli as a function of loneliness. Further, two separate ANCOVAs were conducted using social anxiety and depression as covariates in the analyses. Following these analyses, two new variables for each participant were calculated for use in regression analyses; these new variables enabled the control for any differences in threat responding. The first (ST1-RT) was calculated as the average reaction times for social threat pictures minus the average reaction time for non-social threat pictures divided by the sum of average reaction time for social threat and average reaction time for non-social threat pictures. The second (ST1-Rating) new variable was calculated in the same way, but used average valence ratings in the calculation.

Linear regressions were used to examine the relationship between loneliness and these new variables that represent ratings and reaction times to social threat controlling for ratings and reaction times for all threatening pictures. Linear regressions were conducted using the: (1) total score on the loneliness measure as the predictor variable, and (2) the residual of loneliness controlling for social anxiety and depression so the unique predictability of loneliness could be examined. Curvilinear regressions were not conducted in these analyses because the sample size was small and none of the participants' had a loneliness score in the upper quartile of the UCLA loneliness scale. The sample did not include any extreme loneliness scorers.

Unlike the behavioural data analyses in the present study, it was not possible to control for social anxiety and depression in the ERP data analyses by adding these variables as covariates or creating a residual of loneliness. This was because the ERP data needed to be grouped into either a lonely or non-lonely group in order to conduct analyses based on the microstate approach and use source localization techniques (see chapter 5), which provides detailed information on the spatial and temporal dynamics of the brain. Thus, the ERP data presented in this chapter examines electrical brain activity and loneliness (thus not controlling for social anxiety and depression). This is identified as a limitation of the current study in the discussion section.

Electrophysiological pre-processing

Electrophysiological data were first analysed at the individual level. Raw data of each participant were imported and pre-processed in Cartool software (version 3.30; http://brainmapping.unige.ch/Cartool.htm). As in previous studies (e.g., Ortigue et al., 2004, 2008), epochs of analysis were visually inspected for oculomotor (saccades, and blinks), muscles, and other artifacts in addition to an automated threshold rejection criterion of 100 μV. After off-line artifact rejections, one visual event-related potential (VEP), time-locked to the picture onset, was calculated for each condition and each participant. A total of 4 VEPS were computed for each group of participants (lonely, non-lonely) for each condition - social threat, non-social threat, social non-threat and non-social non-threat. These 8 VEPs were computed covering 1000 ms after the onset of the visual stimuli with a 500 ms pre-stimulus baseline. VEPs were baseline corrected, and band-pass filtered between 1 and 30 Hz. VEP data were then recalculated off-line against the average reference, and normalised to their mean global field power (i.e., GFP; Lehmann & Skrandies, 1980), before group-averaging. Channels with corrupted signals and channels showing substantial noise throughout the recording were interpolated to a standard 111-channel electrode array using a three-dimensional spline procedure (i.e. mathematical tool) (Perrin, Pernier, Bertnard, Giard, & Echallier, 1987).

Second-level electrophysiological analyses

Group-averaged data were subsequently processed using The Chicago Electrical NeuroImaging Analytics (CENA) suite (S. Cacioppo, Weiss, Runesha, & Cacioppo, 2014; https://hpenlaboratory.uchicago.edu/page/cena) to identify brain microstates. The notion of discrete brain microstates was introduced in the 1980's by Lehmann and refer to periods of stable (from tens to hundred milliseconds), event-related brain responses (Lehman, 1987; Michel, Seeck & Landis, 1999). CENA has several advantages over prior methods for segmenting the ERP. For instance, unlike previous methods of segmentation (e.g., based on k-cluster analyses) that require a priori specification of the number of stable microstates in an ERP and the parsing of the entire ERP into the specified number of microstates, the identification of brain microstates in CENA is data-driven, and the ERP is parsed into the baseline state, stable microstates, and non-stable transitions between these states.

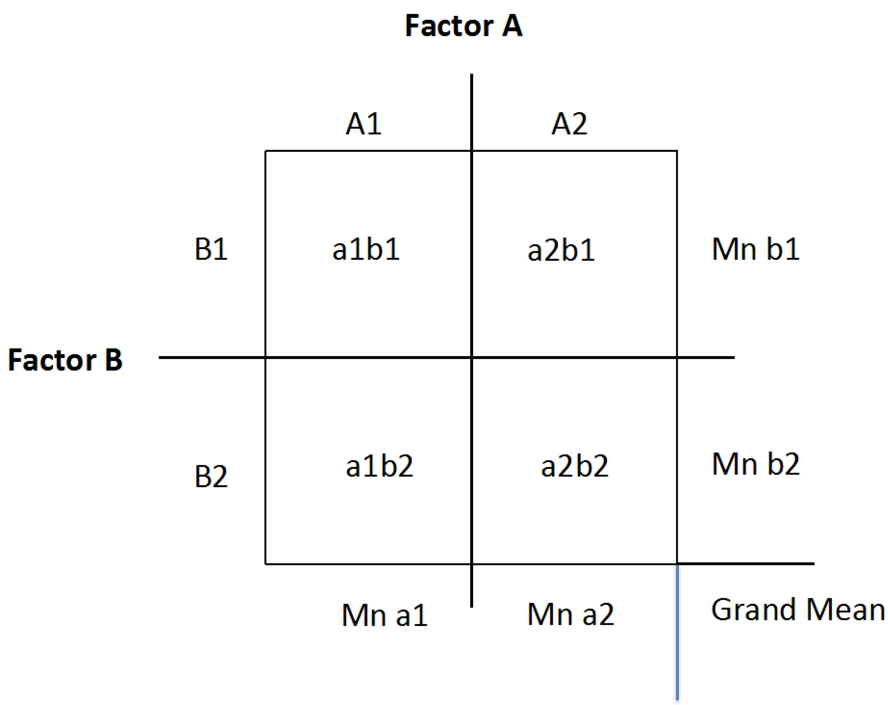
Following the theoretical steps outlined in the paper by Cacioppo et al. (2014), the present investigation focused on event-related microstates, as determined by a root mean square error (RMSE) metric using a lag of 12 ms, a baseline period from which to calculate the noise in the ERP configuration ranging from -496 ms pre-stimulus to 48 ms post-stimulus, and a 99% confidence interval (CI) for identifying potential stable brain microstates and for detecting significant rises or falls in the RMSE function. The series of potential microstates identified across an ERP waveform were then subjected to a cosine metric analysis using a 95% CI to determine whether the successive $n+1^{st}$ microstate differed significantly in configuration from the n^{th} microstate (see S. Cacioppo et al., 2014). The applied version of CENA (version 2014-09-24; S. Cacioppo et al., 2014) was implemented as a plugin in Brainstorm (version 3.2; Tadel, Baillet, Mosher, Pantazis, & Leahy, 2011).

Statistical plans for ERP analyses

In the present research, a priori orthogonal contrasts were conducted to determine differences between lonely and non-lonely individuals in the event-related microstates elicited by social threat and non-social threat stimuli, and a parallel set of orthogonal contrasts were conducted to determine differences between lonely and non-lonely individuals in the event-related microstates elicited by social non-threat and non-social non-threat stimuli during the task. The (level of loneliness: lonely, non-lonely) x 2 (stimulus type: social; non-social) contrasts for the threat (and non-threat) stimuli were performed using CENA (see Figure 6.2).

Figure 6.2: Schematic representation of the between-subject factor A (loneliness) and the within-subject factor B (stimulus type) used for CENA orthogonal contrasts.

In Figure 6.2, *A* represents the between-subjects factor (loneliness), *a1* represents non-lonely, *a2* represents lonely, *B* represents the within-subjects factor (stimulus type), *b1* represents social threat stimuli, and *b2* represents non-social threat stimuli to which participants viewed during the present study.



First, the topographical maps (topo-maps) for the Grand Mean of all conditions were inspected for artifacts or bad channels in the recordings. The Grand Mean was used because it generally represents the best estimate of integrity of the ERP recordings across time and it avoids any confirmatory bias in editing based on any expected differences between conditions. In addition, it was verified that the number of accepted trials from a given subject contributes to each cell of the within-subjects design. The number of accepted trials was equalized across conditions to make sure all conditions had the same number of accepted trials. In the present study, the average number of trials accepted per condition was 21.47.

The main effect test for *A* (level of loneliness) was determined through the following steps using the CENA plug-in available for Brainstorm: (1) Average the a1b1 and a1b2 topo-maps to create the topo-maps for Mn_a1; (2) average the a2b1 and a2b2 topo-maps to create the topo-maps for Mn_a2; (3) difference the Mn_a1 and Mn_a2 topo-maps to create the topo-maps for the main effect for *A* (i.e., calculate (1) – (2)); (4) average the Mn_a1 and Mn_a2 topo-maps to create the topo-maps for the Grand Mean (i.e., average (1) and (2)); (5) perform the CENA on (1) to create the micro-segmentation (and template maps) for Mn_a1; (6) perform the CENA on (2) to create the micro-segmentation (and template maps) for Mn_a2; (7) perform the CENA on (3) to create the micro-segmentation (i.e., epochs of significant difference) between Mn_a1 and Mn_a2 – that is, for the periods of time in which the brain microstates differed as a function of Factor *A*; (8) perform the CENA on (4) to create the micro-segmentation for the periods of time in which the brain microstates did *not* differ as a function of Factor *A*; and (10) in the penultimate step, use the results of (7) when comparing (5) with (6) to determine the epochs during which the evoked brain microstates in Mn_a1 and Mn_a2 differ statistically; (9a) For the epochs in which (7) shows *no* significant differences between (5) and (6), refer to (8) to characterize the evoked brain microstates across Factor A. For such an epoch, source localization was performed on the observed microstate(s) during this epoch in the Grand Mean (i.e., (8)). (9b) For the epochs in which (7) *shows* significant differences between (5) and (6), refer to (5) and (6) to characterize the distinct evoked brain microstates as a function of Factor A. For such an epoch, source localization was performed on the observed microstate(s) during this epoch separately in (4) and in (5).

The main effect test for *B* (stimulus type) was determined using an analogous set of steps as used for the main effect test for *A*. The *A* x *B* interaction test was performed, when possible, by producing simple main effect difference topo-maps *within*-subjects rather than between-subjects to minimize the error in these difference maps. In this example, Factor *A* (level of loneliness) is the between-subjects factor and Factor *B* (stimulus type) is the within-subjects factor, so the simple main effect tests were calculated within each level of *A*.

The interaction test was performed through the following steps: (1') difference the a1b1 and a1b2 topo-maps to create the topo-maps for the simple main effect for a1; (2') difference the a2b1 and a2b2 topo-maps to create the topo-maps for the simple main effect for a2; (3') calculate (1') – (2') to create the topo-maps for the *A* x *B* interaction (i.e., difference of the differences); (4') average the Mn_a1 and Mn_a2 topo-maps to create the topo-maps for the Grand Mean (this average should be available from (4) above); (5') perform the CENA on (1') to create the micro-segmentation (and template maps) for the simple main effect for a1; (6') perform the CENA on (2') to create the micro-segmentation (and template maps) for the simple main effect for a2; (7') perform the CENA on (3') to create the micro-segmentation (i.e., epochs of significant difference) between the simple main effects for a1 and for a2 – that is, for the periods of time during Factors *A* and *B* interacted to produce the observed brain microstates; (8') access the CENA for the Grand Mean, the main effect for Factor *A*, and the main effect for Factor *B* to aid in the following steps; and (9') in the penultimate step in this analysis, use the results of (7') when comparing (5') with (6') to determine the epochs during which the evoked brain microstates in simple main effect a1 and simple main effect a2 differ statistically – that is, the epochs for which there was a significant interaction between Factors *A* and *B*. (9a') For the epochs in which (7') shows *no* significant differences between (5') and (6'), refer to (8') to characterize the evoked brain microstates. Given there is no *A* x *B* interaction during this epoch, inspection of the results in (8') best specify the microstate structure during this epoch. If main effects were also absent for this epoch, then source localization is performed on the observed microstate(s) during this epoch in the Grand Mean. If the main effect for Factor *A* and/or Factor *B* is significant for this epoch, then refer to the results above to characterize the evoked brain microstate(s) observed during this epoch. (9b') For the epochs in which (7') *shows* significant differences between (5') and (6'), refer to (5') and (6') to characterize the distinct evoked brain microstates as a function of Factors *A* and *B*. For such an epoch, source localization should be performed on the observed microstate(s) during this epoch separately in (4') and in (5'). Pairwise comparisons between and source localization within each cell (e.g., a1b1, a1b2, a2b1, & a2b2) may also be performed as a means of breaking down the interaction to all possible pairwise comparisons.

The main effect tests are constructed prior to the interaction test because the latter requires waveforms constructed when testing main effects. However, the interpretation of the results begins with the interaction test to determine what periods of the ERP differ significantly, and what is the microstate(s) that are responsible for any such differences. The use of orthogonal contrasts and 95% and 99% CIs maintain an alpha error of less than .05 in the ERP results reported.

Distributed cortical source estimations

As a final step, the brain generators of every stable microstate were estimated using a cortical source estimation package implemented in Brainstorm (Tadel et al., 2011). Specifically, the forward model was used that was calculated with a symmetric Boundary Element Model (BEM; Gramfort, Papadopoulo, Olivi, & Clerc, 2010; Kybic et al., 2005) generated with OpenMEEG on the cortical surface of a template MNI brain (colin27 atlas) with a 1 mm resolution (Collins et al., 1998; Tzourio-Mazoyer et al., 2002). Cortical source estimations (in picoampere-meters; pAm) were 1) estimated with a constrained inverse model of EEG sources using the standard weighted minimum-norm current estimate (wMNE; Baillet, Mosher & Leahy, 2001) and 2) mapped to a distributed source model consisting of 15,002 elementary current dipoles, as implemented in Brainstorm. The source activity at each cortical location was standardized using the z-score transformation into MNI coordinates (xyz – refer to chapter 5) with respect to the average and standard deviation of the source activity during a 500-ms baseline time window.

Results

Behavioural Results

Reaction times for loneliness

A 2 (level of loneliness: lonely, non-lonely) x 2 (type of stimuli: social, non-social) x 2 (nature of stimuli: threat, non-threat) repeated-measures ANOVA was conducted using reaction time to the images as DV. There were no significant main effects of type of stimuli (F (1, 17) = .18, p = .68, ηp^2 = .010), nature of stimuli (F (1, 17) = .18, p = .68, ηp^2 = .010) and lonely group (F (1, 17) = .007, p = .94, ηp^2 = .000). There were no significant interaction effects for; type of stimuli and lonely group (F (1, 17) = .71, p = .41, ηp^2 = .040), nature of stimuli and lonely group (F (1. 17) = .61, p = .44, ηp^2 = .035), type of stimuli and nature of stimuli (F (1, 17) = 1.76, p = .20, ηp^2 = .094). There was also a non-significant three-way interaction effect between type of stimuli, nature of stimuli and lonely group (F (1, 17) = .65, p = .43, ηp^2 = .037). Table 6.1 details the descriptive statistics.

Linear analysis revealed a non-significant effect between loneliness and reaction times using ST1-RT (reaction time to social threat controlling for reaction time for all threatening pictures) metric (β = .21, p = .40).

Table 6.1: Mean reaction times (and standard deviations) in milliseconds for the four conditions for lonely and non-lonely participants

Picture type	**Lonely**	**Non-lonely**
Social threat	595.85 (199.66)	523.74 (222.06)
Non-social threat	569.63 (342.26)	611.29 (226.68)
Social non-threat	579.64 (159.84)	606.71 (249.16)
Non-social non-threat	518.04 (104.38)	548.62 (158.53)

Note: using the mean loneliness score of 42.26; 10 of the participants were grouped as lonely, while 9 participants were grouped as non-lonely

Reaction times for loneliness whilst controlling for social anxiety and depression

A 2 (level of loneliness: lonely, non-lonely) x 2 (type of stimuli: social, non-social) x 2 (nature of stimuli: threat, non-threat) repeated-measures ANCOVA with social anxiety and depression as covariates was conducted using reaction time as DV. There were no significant main effects of type of stimuli (F (1, 15) = .44, p = .52, ηp^2 = .028), nature of stimuli (F (1, 15) = .01, p = .95, ηp^2 = .000) and lonely group (F (1, 15) = .04, p = .85, ηp^2 = .003). There were no significant interaction effects for type of stimuli and lonely group (F (1, 15) = .26, p = .62, ηp^2 = .017), nature of stimuli and lonely group (F (1. 15) = 1.00, p = .33, ηp^2 = .063), type of stimuli and nature of stimuli (F (1, 15) = 1.00, p = .33, ηp^2 = .062). There was also a non-significant three-way interaction effect between type of stimuli, nature of stimuli and lonely group (F (1, 15) = 1.98, p = 1.80, ηp^2 = .117). Table 6.2 details the descriptive statistics.

Using the residual of loneliness, controlling for social anxiety and depression in the analyses for the ST1-RT metric, a non-significant linear effect (β = .26, p = .28) was found.

Table 6.2: Mean reaction times (and standard error) in milliseconds for the four conditions for lonely and non-lonely participants controlling for social anxiety and depression in the analyses

Picture type	**Lonely**	**Non-lonely**
Social threat	640.31 (86.00)	474.34 (92.46)
Non-social threat	575.19 (118.18)	605.11 (127.06)
Social non-threat	562.93 (83.78)	625.29 (90.07)
Non-social non-threat	543.17 (51.81)	520.08 (55.70)

Valence Ratings for loneliness

Analyses of the behavioural data confirmed that the manipulation of valence was successful and that the stimuli were comparable for lonely and non-lonely individuals. A 2 (level of loneliness: lonely, non-lonely) x 2 (type of stimuli: social, non-social) x 2 (nature of stimuli: threat, non-threat) repeated-measures ANOVA was conducted using valence ratings for the images as DV. There was a significant main effect found for type of stimuli (F (1, 17) = 25.02, p < .001, ηp^2 = .595), with means showing higher negative valence ratings for social pictures compared to non-social pictures. There was also a significant main effect found for nature of stimuli (F (1, 17) = 158.93, p < .001, ηp^2 = .903), with means showing higher negative valence ratings for threat pictures compared to non-threat pictures. There was a non-significant main effect of lonely group (F (1, 17) = 1.16, p = .30, ηp^2 = .064). There were no significant interaction effects for; type of stimuli and lonely group (F (1, 17) = .08, p = .78, ηp^2 = .005), nature of stimuli and lonely group (F (1, 17) = .001, p = .97, ηp^2 = .000), type of stimuli and nature of stimuli (F (1, 17) = 2.08, p = .17, ηp^2 = 109). There was also a non-significant three-way interaction effect between type of stimuli, nature of stimuli and lonely group (F (1, 17) = .58, p = .46, ηp^2 = .033). Table 6.3 shows descriptive statistics for valence ratings by lonely group.

Linear analysis for valence ratings using ST1-Rating (valence ratings for social threat controlling for valence ratings for all threatening pictures) metric revealed a non-significant linear (β = -.21, p = .39) association between loneliness and valence ratings for the social threat pictures.

Table 6.3: Mean valence ratings (and standard deviations) for the four conditions for lonely and non-lonely participants

Picture type	**Lonely**	**Non-lonely**
Social threat	-1.69 (0.36)	-1.67 (0.25)
Non-social threat	-0.93 (0.86)	-0.65 (0.91)
Social non-threat	0.63 (0.67)	0.81 (0.82)

Non-social non-threat	1.23 (0.37)	1.31 (0.39)

Note: Lonely group was defined by a loneliness score above the mean 42.26 (*N* = 10) and non-lonely group was defined by a loneliness score below the mean (*N* = 9)

Valence Ratings for loneliness whilst controlling for social anxiety and depression

A 2 (level of loneliness: lonely, non-lonely) x 2 (type of stimuli: social, non-social) x 2 (nature of stimuli: threat, non-threat) repeated-measures ANCOVA with social anxiety and depression as covariates was conducted using valence ratings as DV. There was a non-significant main effect for type of stimuli (F (1, 15) = 1.78, p = .20, ηp^2 = .106), There was a significant main effect found for nature of stimuli (F (1, 15) = 7.24, p < .05, ηp^2 = .326), with means showing higher negative valence ratings for threat pictures compared to non-threat pictures. There was a non-significant main effect of lonely group (F (1, 15) = 1.18, p = .30, ηp^2 = .073). There were no significant interaction effects for; type of stimuli and lonely group (F (1, 15) = .76, p = .40, ηp^2 = .048), nature of stimuli and lonely group (F (1, 15) = .05, p = .82, ηp^2 = .003), There was a significant interaction effect for type of stimuli and nature of stimuli (F (1, 15) = 12.97, p < .005, ηp^2 = 464), with means showing higher negative valence ratings for social threat and non-social threat pictures compared to social non-threat and non-social non-threat pictures. There was a non-significant three-way interaction effect between type of stimuli, nature of stimuli and lonely group (F (1, 15) = 1.91, p = .19, ηp^2 = .113). Table 6.4 shows the descriptive statistics.

Using the residual of loneliness, controlling for social anxiety and depression in the analyses for ST1-Rating metric, a non-significant linear effect (β = -.04, p = .86) was observed.

Table 6.4: Mean valence ratings (and standard error) for the four conditions for lonely and non-lonely participants controlling for social anxiety and depression in the analyses

Picture type	Lonely	Non-lonely
Social threat	-1.62 (0.13)	-1.74 (0.14)
Non-social threat	-1.09 (0.33)	-0.47 (0.35)
Social non-threat	0.66 (0.29)	0.78 (0.32)
Non-social non-threat	1.21 (0.16)	1.34 (0.17)

Electrophysiological Results for loneliness

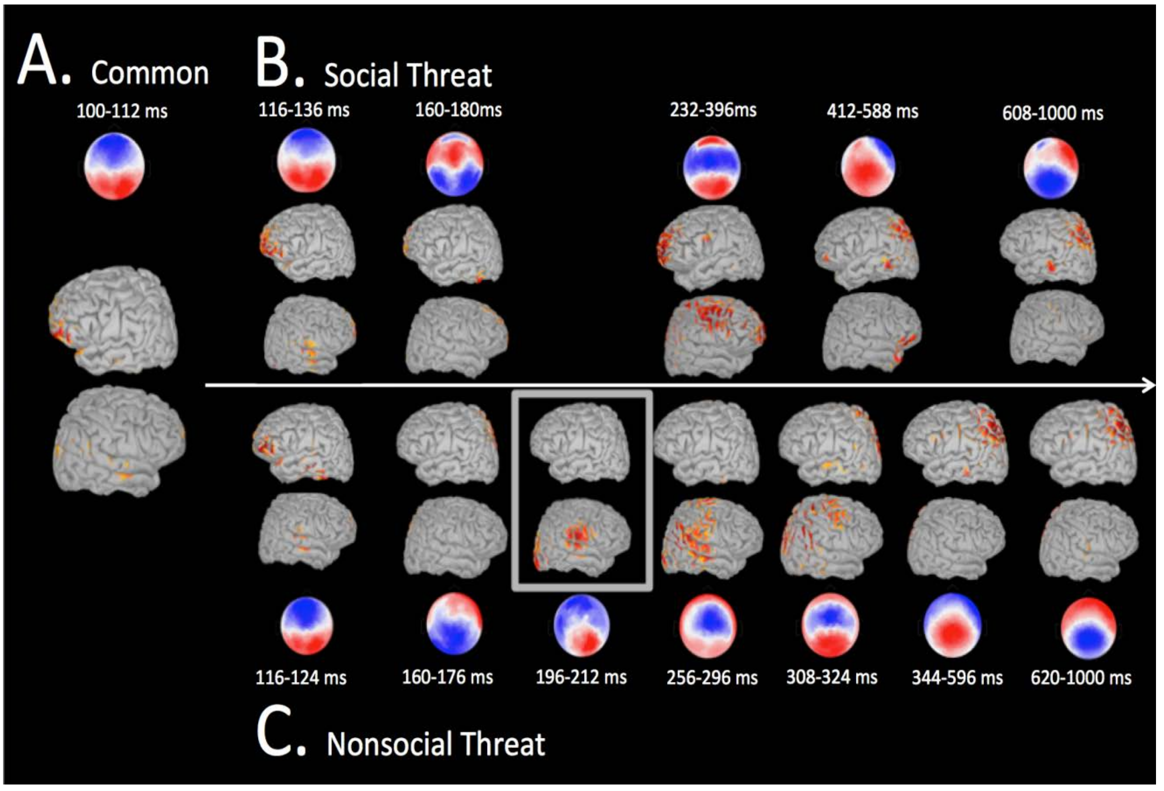
In the present research, a priori orthogonal contrast was conducted to determine differences between lonely and non-lonely individuals in the event-related microstates elicited by social threat and non-social threat. The 2 (loneliness group: lonely, non-lonely) x 2 (stimulus type: social, non-social) CENA contrasts for the threat stimuli were performed following a series of systematic steps described earlier. In the results reported below, the use of orthogonal contrasts and 95% and 99% CIs maintain an alpha error of less than .05.

Social threat and non-social threat stimuli

The 2 x 2 interaction test with level of loneliness (lonely, non-lonely) and type of stimulus (social threat, non-social threat) was performed to determine whether and when the evoked microstates differed across conditions. This priori contrast is performed across the entire evoked response in 128-dimensional sensor space (i.e., the evoked configuration, not single electrode sites) with statistically significant differences in evoked microstates identified by confidence intervals (see S. Cacioppo et al., 2014). The interaction contrast revealed significant differences in the evoked brain response for the periods ranging from 252 ms and 368 ms; 384 ms and 540 ms; 556 and 824 ms; and again from 840 ms to the end of the recording epoch (i.e., 1000 ms).

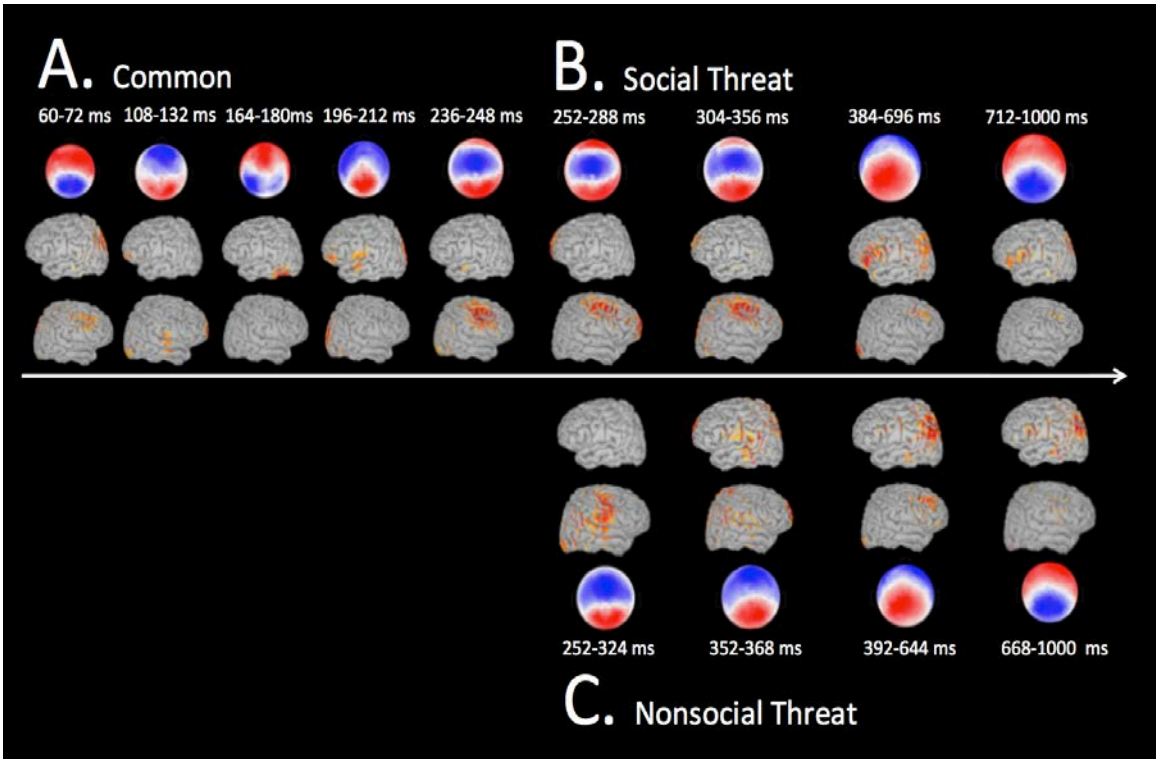
The ERP waveform in 128 dimensional sensor space was next investigated by performing simple main effect tests within *lonely* participants and within *non-lonely* participants. These priori contrasts were constructed within-participants to ensure the effects of stimulus type on the ERP were examined: (a) within the same set of participants/brains, and (b) across average waveforms calculated from the same number of trials. The first simple effects test contrasted the effects of social threat and non-social threat stimuli in *lonely* participants. The contrast revealed significant differences in the two ERP waveforms as a function of stimulus type for the periods ranging from 116 and 212 ms, and again from 232 to 1000 ms. To determine the evoked microstate(s) prior to 116 ms (and between 212 & 232 ms, which proved to be a transition between microstates), the CENA was performed on the ERP waveform collapsed across stimulus type (since the simple main effect contrast showed no differences as a result of stimulus type), whereas to determine the evoked microstate(s) between 116 and 212 ms and between 232 and 1,000 ms, the CENA was performed separately on the ERP waveforms elicited in lonely participants by the social threat stimuli and on the ERP waveforms elicited in lonely participants by the non-social threat stimuli. The statistically significant results (p < .05), depicted in the Figure 6.3, show that lonely participants have: (a) an initial evoked brain microstate (which did not vary as a function of stimulus type) between 100-112 ms, (b) five additional discrete event-related microstates in response to the social threat stimuli, and (c) seven additional event-related microstates in response to non-social threat stimuli. Finally, the distributed cortical source estimations were performed to investigate the brain generators of each of the evoked microstates. Results are summarized in Table 6.5.

Figure 6.3: Cortical source estimation and template maps for the discrete microstates evoked in lonely individuals common to both conditions (A) or specifically elicited in response to social threat (B) or nonsocial threat (C) stimuli



The second simple effects test contrasted the effects of social threat and non-social threat stimuli in *non-lonely* participants. The contrast revealed significant differences in the two ERP waveforms as a function of stimulus type for the periods ranging from 252 and 368 ms; 384 and 540 ms; 556 and 824; and again from 840 to 1000 ms. That is, the microstate structure prior to 252 ms was defined based on analyses of the ERP collapsed across stimulus type within non-lonely participants, and the microstate structure after 252 ms (inclusive) was defined based on analyses of the ERP within stimulus type for non-lonely participants. The statistically significant results ($p < .05$) are depicted in the Figure 6.4. As suggested by the interaction test, the discrete brain microstates evoked in non-lonely participants by social and nonsocial threat stimuli were quite different than those observed in lonely participants. Specifically, five discrete microstates were evoked in the first 252 ms, and these microstates did not differ as a function of stimulus type (social vs non-social threat). The remaining evoked microstates differed as a function of stimulus type, with four microstates elicited in the social threat stimulus condition, and four microstates elicited in the non-social threat stimulus condition (Figure 6.4). As above, distributed cortical source estimations were next performed to investigate the brain generators of each of the evoked microstates. Results are summarized in Table 6.6.

Figure 6.4: Cortical source estimation and template maps for the discrete microstates evoked in non-lonely individuals common to both conditions (A) or specifically elicited in response to social threat (B) or nonsocial threat (C) stimuli



Social non-threat and non-social non-threat stimuli

A parallel set of orthogonal contrasts were conducted to determine differences between lonely and non-lonely individuals in the event-related microstates elicited by social non-threat and non-social non-threat stimuli during the task. As expected there were no differences in the brain microstates observed in response to the social non-threat and non-social non-threat stimuli.

Table 6.5: Estimated brain coordinates for the discrete microstates evoked in lonely individuals specifically in response to Social Threat (in red), Non-Social Threat (in blue), or common to both conditions (in aqua blue)

Social Threat	Non-Social Threat	Brodmann Areas	Brain region labels	Brain coordinates (MNI)		
				x	y	z
100-112 ms		**BA21**	**Middle temporal gyrus**	**-57**	**-13**	**-11**
				-60	**-34**	**1**
				62	**-39**	**1**
		BA47	**Inferior frontal gyrus**	**-48**	**42**	**-8**
				-46	**23**	**-16**
		BA19	**Associative visual cortex**	**55**	**-65**	**18**
				47	**-77**	**1**
		BA10	**Anterior prefrontal cortex**	**-7**	**54**	**2**
				-13	**59**	**27**
				32	**59**	**-5**
		BA20	**Inferior temporal gyrus**	**59**	**-22**	**-27**
		BA54	Hippocampus	-28	-8	-21
				31	-8	-24
116-136 ms		**BA10**	**Anterior prefrontal cortex**	**-7**	**53**	**1**
		BA19	**Associative visual cortex**	**57**	**-65**	**18**
		BA20	**Inferior temporal gyrus**	**60**	**-21**	**-25**
		BA22	**Superior temporal gyrus**	**64**	**-32**	**18**
		BA36	**Parahippocampus**	**8**	**-42**	**0**
		BA40	**Supramarginal gyrus**	**64**	**-16**	**24**
		BA46	**Dorsolateral prefrontal cortex**	**-47**	**42**	**1**
		BA47	**Inferior frontal gyrus (pars orbitalis)**	**-34**	**32**	**-15**
		BA13	Insula	44	6	2
		BA38	Temporal pole	-29	14	-29
				33	18	-28
		BA45	Inferior frontal gyrus (pars triangularis)	-50	16	2
		BA53	Amygdala	-23	6	-25

160-180 ms		**BA10**	**Anterior prefrontal cortex**	**7**	**64**	**2**
				-7	**54**	**2**
		BA8	**Frontal eye field**	**22**	**47**	**42**
		BA9	**Dorsolateral prefrontal cortex**	**42**	**37**	**23**
		BA21	**Middle temporal gyrus**	**-62**	**-24**	**-19**
		BA19	**Associative visual cortex**	**48**	**-71**	**24**
		BA6	**Supplementary motor area (SMA)**	**48**	**4**	**44**
		BA37	**Fusiform area**	**-59**	**-65**	**-17**
		BA18	Secondary visual cortex	34	-99	-2
232-396 ms		**BA1**	**Somatosensory cortex**	**35**	**-33**	**64**
		BA6	**SMA**	**-7**	**-12**	**66**
		BA7	**Somatosensory association cortex**	**23**	**-48**	**66**
		BA10	**Anterior prefrontal cortex**	**-7**	**53**	**0**
				32	**56**	**-4**
		BA19	**Associative visual cortex**	**48**	**-76**	**3**
		BA37	**Fusiform gyrus**	**-64**	**-56**	**-13**
		BA39	**Angular gyrus**	**50**	**-60**	**25**
		BA46	**Dorsolateral prefrontal cortex**	**-46**	**43**	**3**
		BA39	Angular gyrus	-56	-53	15
		BA44	Inferior frontal gyrus (pars opercularis)	40	12	3
		BA11	Orbitofrontal area	-24	28	-21
				25	28	-21
		BA9	Dorsolateral prefrontal cortex	25	38	35
412-588 ms		**BA4**	**Primary motor cortex**	**-37**	**-32**	**62**
		BA7	**Superior parietal lobule**	**-35**	**-61**	**62**
		BA10	**Anterior prefrontal cortex**	**-39**	**54**	**-12**
		BA11	**Orbitofrontal area**	**9**	**44**	**-24**
		BA13	**Anterior Insula**	**42**	**19**	**-10**
		BA18	**Secondary visual cortex**	**-32**	**-93**	**12**
		BA19	**Associative visual cortex**	**-43**	**-78**	**26**
				-58	**-61**	**5**
		BA20	**Inferior temporal gyrus**	**50**	**7**	**-43**
		BA38	**Middle temporal gyrus**	**50**	**19**	**-40**
		BA39	**Angular gyrus**	**-54**	**-61**	**39**
		BA45	**Inferior frontal gyrus (pars triangularis)**	**51**	**21**	**3**

		BA47	**Inferior frontal gyrus (pars orbitalis)**	**50**	**42**	**-12**
		BA46	Dorsolateral prefrontal cortex	-48	44	-2
608-1000 ms		**BA1**	**Somatosensory cortex**	**-25**	**-31**	**66**
		BA6	**SMA**	**39**	**-11**	**56**
		BA7	**Superior parietal cortex**	**-9**	**-70**	**56**
		BA13	**Anterior insula**	**44**	**15**	**-11**
		BA19	**Associative visual cortex**	**-19**	**-90**	**38**
		BA21	**Middle temporal gyrus**	**-71**	**-41**	**-3**
		BA37	**Fusiform gyrus**	**-64**	**-47**	**-2**
		BA39	**Angular gyrus**	**-56**	**-55**	**29**
		BA40	**Supramarginal gyrus**	**-47**	**-37**	**48**
		BA47	**Inferior frontal gyrus (pars orbitalis)**	**55**	**33**	**-11**
		BA38	Middle temporal gyrus	51	17	-39
	116-124 ms	**BA21**	**Middle temporal gyrus**	**-59**	**-14**	**-8**
				-60	**-26**	**-17**
			Posterior superior temporal sulcus (pSTS)	**62**	**-36**	**-1**
		BA47	**Inferior frontal gyrus (pars orbitalis)**	**-49**	**40**	**-8**
		BA13	**Anterior insula**	**-37**	**16**	**-8**
		BA54	**Hippocampus**	**17**	**-37**	**4**
		BA10	**Anterior prefrontal cortex**	**-28**	**62**	**-14**
				-17	**62**	**16**
				32	**57**	**-4**
		BA37	**Fusiform gyrus**	**-60**	**-57**	**-12**
		BA54	Hippocampus	-31	-22	-16
		BA7	Superior parietal lobule	25	-73	55
		BA40	Supramarginal gyrus	38	-40	53
		BA39	Angular gyrus	56	-51	26
		BA36	Parahippocampus	-18	-33	-6
				18	-34	-6

	160-176 ms	**BA19**	**Associative visual cortex**	**-13**	**-88**	**46**
		BA39	**Superior angular gyrus**	**34**	**-81**	**39**
		BA7	**Superior parietal lobule**	**6**	**-59**	**55**
				6	**-48**	**69**
		BA6	**SMA**	-13	-7	73
		BA40	Supramarginal gyrus	-54	-22	33
		BA37	Fusiform gyrus	-69	-49	-8
		BA44	Inferior frontal gyrus (pars opercularis)	51	9	27
	196-212 ms	**BA4**	**Primary motor area**	**68**	**-3**	**14**
		BA40	**Supramarginal gyrus**	**67**	**-16**	**23**
		BA39	**Angular gyrus**	**49**	**-58**	**14**
				54	**-48**	**35**
		BA41	**Superior temporal gyrus**	**69**	**-14**	**-4**
		BA19	**Associative visual cortex**	**47**	**-76**	**5**
		BA18	**Secondary visual cortex**	**33**	**-97**	**-13**
		BA21	**Middle temporal gyrus**	**69**	**-38**	**1**
		BA22	**Posterior superior temporal sulcus**	**69**	**-36**	**14**
		BA20	Inferior temporal gyrus	43	-21	-29
		BA47	Inferior frontal gyrus (pars orbitalis	-34	30	-18
		BA18	Secondary visual cortex	-13	-91	-15
		BA37	Fusiform gyrus	-63	-56	-15
				59	-54	-13
	256-296 ms	**BA19**	**Associative visual cortex**	**49**	**-78**	**6**
				55	**-67**	**21**
		BA39	**Superior Angular gyrus area**	**47**	**-70**	**36**
		BA31	**Dorsal posterior cingulate cortex**	**11**	**-44**	**51**
		BA7	**Superior parietal lobule**	**37**	**-44**	**57**
				31	**-72**	**44**
		BA21	**Middle temporal gyrus (Inferior part)**	**64**	**-35**	**-21**
			Middle temporal gyrus (Superior part)	**64**	**-28**	**-4**
			Middle temporal gyrus (Anterior part)	**70**	**-17**	**-13**
		BA13	**Insula**	**49**	**6**	**-2**
		BA6	**SMA**	**44**	**-13**	**61**
				21	**-13**	**76**

		BA22	**Superior temporal gyrus**	**70**	**-28**	**5**
		BA18	**Secondary visual cortex**	**20**	**-103**	**8**
				29	**-95**	**-13**
		BA37	Fusiform gyrus	-67	-54	-14
		B54	Hippocampus	30	-21	-14
		BA20		44	-21	-30
		BA4	Primary motor cortex	-42	-21	55
		BA6	SMA	39	7	57
				-30	-13	59
	308-324 ms	**BA1**	**Somatosensory cortex**	**-30**	**-32**	**66**
				32	**-32**	**66**
		BA18	**Secondary visual cortex**	**-21**	**-99**	**11**
		BA19	**Associative visual cortex**	**55**	**-63**	**7**
		BA6	**SMA**	**-19**	**-5**	**72**
				52	**-5**	**52**
		BA31	**Dorsal anterior cingulate**	**-7**	**-38**	**54**
		BA37	**Fusiform gyrus**	**-61**	**-55**	**-14**
				60	**-55**	**-12**
		BA39	**Angular gyrus**	**53**	**-63**	**23**
				-55	**-55**	**30**
		BA40	Dorsolateral posterior cingulate cortex	-45	-32	44
	344-596 ms	**BA1**	**Somatosensory cortex**	**-28**	**-30**	**66**
		BA7	**Superior parietal lobule**	**-22**	**-60**	**72**
		BA18	**Secondary visual cortex**	**-28**	**-94**	**13**
		BA19	**Associative visual cortex**	**-43**	**-80**	**24**
		BA21	**Middle temporal gyrus (Superior part)**	**-63**	**-45**	**0**
		BA44	**Inferior frontal gyrus (pars opercularis)**	**-57**	**15**	**12**
		BA40	**Supramarginal gyrus**	**-58**	**-22**	**39**
		BA6	**SMA**	**-16**	**-7**	**70**
		BA21	Middle temporal gyrus (Superior part)	58	-35	-5
		BA40	Supramarginal gyrus	62	-18	27
		BA6	SMA	32	-18	63
		BA8	Frontal eye field	24	22	45
		BA38	Temporo-polar area	52	15	-26
		BA1	**Somatosensory cortex**	**-31**	**-32**	**66**
		BA7	**Superior parietal lobule**	**-34**	**-62**	**63**
		BA40	**Supramarginal gyrus**	**59**	**-38**	**29**
				-58	**-20**	**36**
		BA19	**Associative visual cortex**	**-42**	**-77**	**22**

	620-1000 ms	**BA44**	**Inferior frontal gyrus (pars opercularis)**	**-54**	**15**	**8**
		BA39	**Angular gyrus**	**57**	**-50**	**26**
		BA21	**Middle temporal gyrus (Superior part)**	**56**	**-35**	**-5**
		BA6	**SMA**	**-42**	**12**	**49**
		BA19	Associative visual cortex	54	-63	9
		BA9	Dorsolateral prefrontal cortex	42	22	28
		BA47	Inferior frontal gyrus (pars orbitalis)	-55	41	-1
		BA13	Anterior insula	41	22	-7
				-36	22	-5

Local maxima of current source density obtained from wMNE brain source estimations. Local maxima are in MNI coordinates. In bold, the maxima with an amplitude greater than 70% are provided in the table. In grey, the maxima with a lower amplitude (> 51% with a minimum size of 10). Stable brain microstates elicited in response to social threat are indicated in red, while stable brain microstates elicited in response to non-social threat are indicated in blue, and common brain microstates (collapsed across stimulus type) are highlighted in aqua blue.

Table 6.6: Estimated brain coordinates for the discrete microstates evoked in non-lonely individuals specifically in response to Social Threat (in red), Non-Social Threat (in blue), or common to both conditions (in aqua blue)

Social Threat	Non-Social Threat	Brodmann Areas	Brain region labels	Brain coordinates (MNI) x	y	z
60-72 ms		**BA9**	**Dorsolateral prefrontal cotex**	**36**	**35**	**42**
		BA8	**Frontal eye field**	**47**	**23**	**42**
		BA39	**Angular gyrus**	**-49**	**-64**	**26**
		BA19	**Associative visual cortex**	**-18**	**-91**	**38**
				29	**-91**	**20**
		BA7	**Superior parietal lobule**	**23**	**-50**	**64**
		BA1	**Primary somatosensory cortex**	**22**	**-37**	**70**
		BA6	**SMA**	**22**	**-2**	**66**
		BA6	SMA	-10	-10	72
		BA40	Supramarginal gyrus	63	-18	23
		BA39	Angular gyrus	55	-64	23
		BA54	Hippocampus	-24	-37	0
		BA37	Fusiform area	-64	-48	-4
108-132 ms		**BA46**	**Dorsolateral prefrontal cortex**	**-46**	**44**	**4**
		BA10	**Anterior prefrontal cotex**	**-6**	**52**	**2**
				18	**68**	**2**
		BA13	**Insula**	**45**	**5**	**2**
		BA19	**Associative visual cortex**	**17**	**-83**	**43**
		BA36	**Parahippocampus**	**17**	**-32**	**-6**
		BA39	**Angular gyrus**	**54**	**-66**	**21**
		BA40	**Supramarginal gyrus**	**66**	**-18**	**22**
		BA22	**Superior temporal gyrus**	**68**	**-15**	**2**
		BA21	**Middle temporal gyrus**	**68**	**-13**	**-13**
		BA18	**Secondary visual cortex**	**34**	**-90**	**-5**
		BA21	Middle temporal gyrus	-61	-33	2
		BA36	Parahippocampus	-20	-31	-7
		BA18	Secondary visual cortex	-7	-103	-12
		BA54	Hippocampus	31	-9	-23
				-29	-9	-22
		BA20	Inferior temporal gyrus	-52	-9	-28
164-180 ms		**BA37**	**Fusiform gyrus**	**-59**	**-66**	**-3**
		BA21	Middle temporal gyrus	-61	-31	2
		BA18	Secondary visual cortex	-2	-100	-10

196-212 ms	**BA39**	**Angular gyrus**	**52**	**-62**	**24**
			-57	**-55**	**17**
	BA7	**Superior parietal lobule**	**21**	**-74**	**56**
	BA19	**Associative visual cortex**	**23**	**-87**	**42**
			-38	**-87**	**15**
	BA18	**Secondary visual cortex**	**-37**	**-87**	**-12**
			29	**-94**	**-12**
	BA37	**Fusiform gyrus**	**-60**	**-58**	**-12**
	BA47	**Inferior frontal gyrus (pars orbitalis)**	**-42**	**27**	**-15**
	BA10	**Anterior prefrontal cortex**	**-47**	**48**	**-10**
	BA40	**Supramarginal gyrus**	**-64**	**-24**	**17**
	BA21	**Middle temporal gyrus**	**-66**	**-11**	**-18**
	BA4	Primary motor cortex	-66	-4	11
	BA20	Inferior temporal gyrus	41	-11	-40
	BA54	Hippocampus	-31	-11	-23
	BA6	SMA	46	-11	49
	BA37	Fusiform gyrus	59	-55	-11
	BA13	Posterior Insula	-42	-13	7
	BA13	Anterior Insula	-38	17	-7
	BA40	Supramarginal gyrus	66	-20	24
236-248 ms	**BA18**	**Secondary visual cortex**	**11**	**-71**	**24**
			-35	**-88**	**-13**
	BA7	**Superior parietal lobule**	**25**	**-71**	**49**
	BA39	**Angular gyrus**	**47**	**-59**	**42**
	BA8	**Frontal eye field**	**38**	**28**	**42**
	BA19	**Associative visual cortex**	**18**	**-85**	**44**
			-14	**-82**	**44**
	BA21	**Middle temporal gyrus**	**-67**	**-12**	**-8**
	BA6	**SMA**	**45**	**-14**	**62**
	BA41	**Auditory cortex**	**58**	**-14**	**7**
	BA44	**Inferior frontal gyrus (pars opercularis)**	**42**	**15**	**1**
	BA10	**Anterior prefrontal cortex**	**43**	**48**	**-4**
	BA37	Fusiform gyrus	-61	-56	-13
			47	-63	-19
	BA36	Parahippocampus	19	-33	-5
			-18	-35	-5
	BA45	Inferior frontal gyrus (pars triangularis)	51	23	-1
	BA13	Insula	44	-3	6
	BA7	Superior parietal lobule	-26	-71	43
	BA39	Angular gyrus	-48	-63	23

252-288 ms		**BA10**	**Anterior prefrontal cortex**	**30**	**55**	**15**
				-5	**52**	**1**
		BA8	**Frontal eye field**	**42**	**22**	**46**
		BA6	**SMA**	**42**	**3**	**55**
		BA4	**Primary motor cortex**	**47**	**-15**	**60**
		BA39	**Angular gyrus**	**47**	**-59**	**44**
		BA7	**Superior parietal lobule**	**32**	**-77**	**44**
		BA46	Dorsolateral prefrontal cortex	-42	40	7
		BA39	Angular gyrus	-50	-62	7
		BA19	Associative visual cortex	48	-77	5
304-356 ms		**BA19**	**Associative visual cortex**	**48**	**-77**	**5**
				-38	**-86**	**14**
		BA39	**Angular gyrus**	**43**	**-59**	**50**
				56	**-63**	**20**
		BA10	**Anterior prefrontal cortex**	**43**	**49**	**-5**
		BA8	**Frontal eye field**	**43**	**12**	**53**
		BA18	**Secondary visual cortex**	**-20**	**-97**	**15**
		BA10	Anterior prefrontal cortex	-33	55	-8
		BA32	Dorsal anterior cingulate cortex	7	41	-4
		BA39	Angular gyrus	-53	-53	27
		BA37	Fusiform gyrus	-59	-53	-14
		BA10	Anterior prefrontal cortex	-24	48	27
		BA13	Anterior Insula	40	16	2
384-696 ms		**BA45**	**Inferior frontal gyrus (pars triangularis)**	**-54**	**37**	**2**
		BA9	**Dorsolateral prefrontal cortex**	**-29**	**37**	**31**
				40	**36**	**34**
		BA44	**Inferior frontal gyrus (pars opercularis)**	**-52**	**15**	**6**
		BA21	**Middle temporal gyrus**	**-63**	**-42**	**6**
		BA1	**Primary somatosensory cortex**	**-56**	**-23**	**31**
		BA19	**Associative visual cortex**	**34**	**-87**	**25**
		BA44	Inferior frontal gyrus (pars opercularis)	53	18	4
		BA13	Anterior Insula	40	25	-4
		BA10	**Anterior prefrontal cortex**	**-33**	**55**	**-7**
		BA13	**Anterior Insula**	**-40**	**15**	**-7**
		BA44	**Inferior frontal gyrus (pars opercularis)**	**-53**	**15**	**6**
		BA40	**Supramarginal gyrus**	**-62**	**-24**	**21**
		BA21	**Middle temporal gyrus**	**-64**	**-46**	**0**
		BA1	**Primary somatosensory**	**-27**	**-30**	**67**

712-1000 ms			cortex			
		BA39	Angular gyrus	-54	-55	29
				-55	-60	5
		BA19	Associative visual cortex	-45	-74	18
		BA8	Frontal eye field	45	14	43
		BA39	Angular gyrus	34	-81	39
		BA31	Dorsal posterior cingulate cortex	-5	-50	45
		BA7	Superior parietal lobule	26	-50	64
		BA44	Inferior frontal gyrus (pars opercularis)	59	11	18
		BA54	Hippocampus	-24	-39	1
	252-324 ms	BA40	Supramarginal gyrus	67	-19	21
		BA21	Middle temporal gyrus	62	-37	1
		BA1	Primary somatosensory cortex	21	-34	69
		BA6	SMA	-9	-10	69
		BA4	Primary motor cortex	47	-10	54
		BA19	Associative visual cortex	47	-76	6
		BA39	Angular gyrus	50	-60	25
		BA20	Inferior temporal gyrus	44	-20	-33
		BA36	Parahippocampus	31	-20	-15
		BA40	Supramarginal gyrus	-54	-20	36
		BA39	Angular gyrus	-54	-55	26
		BA37	Fusiform gyrus	-60	-55	-12
		BA13	Anterior Insula	37	15	4
	352-368 ms	BA10	Anterior prefrontal cortex	14	73	2
				-5	53	1
		BA32	Dorsal anterior cingulate cortex	-4	51	2
				7	42	9
		BA21	Middle temporal gyrus	-64	-48	2
		BA39	Angular gyrus	53	-49	32
				-51	-63	24
		BA7	Superior parietal lobule	-36	-62	51
				7	-57	49
		BA37	Fusiform gyrus	-61	-57	-13
		BA6	SMA	7	-16	72
		BA19	Associative visual cortex	47	-75	1
		BA40	Supramarginal gyrus	64	-16	21
		BA13	Anterior Insula	42	22	-5
		BA11	Orbitofrontal area	-14	62	-13
		BA54	Hippocampus	27	-5	-23
				-29	-26	-31

		BA6	SMA	-29	-5	57
		BA8	Frontal eye field	-16	34	51
		BA36	Parahippocampus	-21	-26	-12
				21	-26	-12
		BA37	Fusiform gyrus	28	-26	-28
		BA21	Middle temporal gyrus	62	-26	-8
	392-644 ms	**BA44**	**Inferior frontal gyrus (pars opercularis)**	**52**	**19**	**5**
				-58	**10**	**27**
		BA40	**Supramarginal gyrus**	**-57**	**-23**	**31**
		BA39	**Angular gyrus**	**-57**	**-56**	**29**
		BA21	**Middle temporal gyrus**	**-64**	**-45**	**1**
		BA19	**Associative visual cortex**	**-42**	**-83**	**21**
				12	**-85**	**45**
		BA1	**Primary somatosensory cortex**	**-42**	**-32**	**42**
		BA6	**SMA**	**-42**	**10**	**45**
		BA9	**Dorsal prefrontal cortex**	**40**	**34**	**32**
		BA13	**Anterior insula**	**40**	**24**	**-3**
		BA6	SMA	29	-16	62
		B47	Inferior frontal gyrus (pars orbitalis)	42	25	-2
	668-1000 ms	**BA4**	**Primary motor cortex**	**45**	**-12**	**52**
		BA8	**Frontal eye field**	**46**	**14**	**41**
		BA44	**Inferior frontal gyrus (pars opercularis)**	**59**	**14**	**12**
		BA39	**Angular gyrus**	**43**	**-58**	**47**
				-54	**-55**	**28**
		BA19	**Associative visual cortex**	**12**	**-90**	**36**
				-36	**-88**	**29**
		BA37	**Fusiform gyrus**	**-59**	**-55**	**-13**
		BA40	**Supramarginal gyrus**	**-58**	**-21**	**35**
		BA6	**SMA**	**-58**	**9**	**29**
		BA21	**Middle temporal gyrus**	**-69**	**-38**	**-12**
		BA1	**Primary somatosensory cortex**	**-42**	**-32**	**46**
		BA45	Inferior frontal gyrus (pars triangularis)	54	19	1
		BA46	Dorsolateral prefrontal cortex	-37	30	14
		BA13	Anterior Insula	41	23	-4
		BA21	Middle temporal gyrus	55	-38	-4

Local maxima of current source density obtained from wMNE brain source estimations. Local maxima are in MNI coordinates. In bold, the maxima with an amplitude greater than 70% are provided in the table. In grey, the maxima with a lower amplitude (> 51% with a minimum size of 10). Stable brain microstates elicited in response to social threat are indicated in red, while stable brain microstates elicited in response to non-social threat are indicated in blue, and common brain microstates (collapsed across stimulus type) are highlighted in aqua blue.

Discussion

Prior behavioural research and studies 1 and 5 of this thesis suggest that lonely people show automatic (non-conscious) attentional biases for social threats. The goal of the present study was to investigate the spatio-temporal dynamics of the event-related brain microstates elicited by social threat and non-social threat in lonely and non-lonely individuals. The behavioural data confirmed that lonely and non-lonely participants rated the experimental stimuli similarly to that observed in prior fMRI studies (Cacioppo et al., 2009), confirming the comparability of the experimental stimuli for both groups. The behavioural findings showed that lonely individuals did not rate the social threat pictures more negatively or respond faster to these images compared to non-lonely individuals, suggesting that hypervigilance to social threat may not occur at an explicit level. Also, these behavioural findings did not change as a function of loneliness after controlling for social anxiety and depression in the analyses. The study hypothesized for the neuroimaging data that lonely compared to non-lonely individuals would elicit greater visual cortical activation in response to social threat than non-social threat pictures. Also, non-lonely compared to lonely individuals would elicit greater activation in the posterior temporal regions (including the TPJ) in response to social threat than non-social threat pictures. These two effects were found in a prior fMRI study that contrasted unpleasant social and unpleasant non-social stimuli (Cacioppo et al., 2009).

The interaction test indicated there were no significant differences in the early brain microstates evoked as a function of stimulus type in lonely and non-lonely participants, whereas differences were found in the evoked microstates beginning approximately 250 ms following stimulus onset. In the *lonely* participants, three discrete microstates were evoked by pictures of social threat, whereas four microstates were evoked by pictures of non-social threat. As is evident in Figure 6.3, the microstate from 232-396 ms in the social threat condition began before and ended well after the two microstates in the non-social threat condition over the comparable post-stimulus period. Source localization estimates suggested that the brain microstate elicited during this period in response to social threats involved extensive prefrontal regions characteristic of response preparation and control. The brain regions in the first of the two microstates evoked in response to non-social threats during this time period shared some of the same neural substrates as the microstate evoked by social threats but included a much wider range of regions which were activated much more briefly. The second of these two microstates, also activated much more briefly, differed in that the non-social threat was associated with activation in more posterior regions (e.g., secondary visual cortex, posterior cingulate cortex) and fewer anterior (e.g., frontal cortex) regions.

In contrast to the lonely participants, the *non-lonely* participants showed a later differentiation in microstates as a function of stimulus type and a somewhat similar microstate structure in response to social and non-social threats (see Figure 6.4). For instance, both the social and the non-social threat elicited four discrete microstates within the first 250 ms post-stimulus onset, and four other discrete microstates beginning at 252 ms, with the first of these evoked by social threat ranging from 252-288 ms and the first of the microstates evoked by non-social threat ranging from 252-324 ms. Source estimations of these microstates revealed somewhat similar generators for both social and non-social stimuli within brain networks associated with emotional processing, attention, and perspective taking, with the exception that non-social (threat) stimuli activated more brain areas associated with biological motion whereas social stimuli (threat) activated more areas associated with social cognition (Cacioppo et al., 2009; Mitchell, 2008; Mitchell, Banaji, & Macrae, 2005; Mitchell, Heatherton, & Macrae, 2002; Sakaki, Niki, & Mather, 2012).

Interestingly, simple main effects tests within lonely participants suggested that the elicited brain microstates in lonely participants differed early for social and non-social threats, with fewer discrete microstates elicited by social threat than non-social threats. However, the simple main effects tests within the non-lonely participants reflected a number of discrete brain microstates that were common across both social threat and non-social threat. For instance, differences in brain microstates as a function of stimulus type emerged in lonely participants as early as 116 ms following the stimulus onset, whereas this distinction was not observed until 252 ms in non-lonely participants. This finding provides support for the notion that the *implicit* vigilance for social threat is higher in lonely than non-lonely individuals (Cacioppo & Hawkley, 2009).

In the social threat condition, the first of the separable microstates in *lonely* participants ranged from 116-136 ms, whereas the first of these microstates in the non-social threat condition lasted less than half as long (116-124 ms) and was associated with estimated activation in a largely different set of neural regions (see Table 6.5). For instance, in lonely the microstate evoked from 116-136 ms by social threat was estimated to be associated with activation in regions including the associative visual cortex, the inferior and superior temporal gyrus, the parahippocampus, the supramarginal gyrus, the dorsolateral prefrontal cortex, and possibly the amygdala and insula – regions associated with attention and threat, whereas the microstate evoked from 116-124 ms by non-social threat was estimated to be associated with activation in regions including the posterior superior temporal sulcus, middle temporal gyrus, TPJ, fusiform gyrus, and hippocampus – regions associated with biological motion perception, face perception, and episodic memory. Given the pictures of non-social threats included the face of a threatening animal (i.e. snake), it is interesting that the early microstates elicited in lonely individuals by social threats tend to reflect attention and the orchestration of responses to threat, whereas the early microstates elicited by non-social threats tend to reflect the more nuanced processes of social perception and episodic memory. The above finding is consistent with the hypervigilance to social threat hypothesis in loneliness.

One limitation of the above study is that the negative affect of loneliness could not be examined by controlling for social anxiety and depression in the neuroimaging results using the CENA approach. Future studies could address this limitation by collecting data from a large number of participants and creating two levels of each separate variable (e.g. lonely, socially-anxious, depressed group and non-lonely, non socially-anxious, non-depressed group). This would be important for prospective studies because the speed of threat processing and brain regions activated in the current study by social threat pictures in lonely individuals may concur with timings and brain regions activated in socially anxious and/or individuals with depression. For example, in a recent review of neuroimaging in social anxiety, Brühl, Delsignore, Komossa, and Weidt (2014) reported that the fear circuitry – amygdala, insula, anterior cingulate and prefrontal cortex was more activated in socially anxious individuals compared to non-socially anxious individuals during specific (negative facial expressions or social situations) and unspecific (anticipation of stimuli or cognitive) tasks. Also, the medial parietal and occipital regions were more activated in socially anxious individuals in response to tasks. EEG studies that provide information regarding the timings of neural events have found that the speed of threat processing is automatic and quicker for socially anxious individuals compared to non-socially anxious individuals. In addition, early ERP components associated with vigilance and attention such as P1, P2 and N2 were found to be enhanced for socially anxious individuals when viewing social threats (e.g. negative facial expressions) compared to neutral stimuli (Schulz, Mothes-Lasch & Straube, 2013).

Similarly, neuroimaging in individuals with depressive symptoms show more activity in the amygdala, fusiform, insula and parahippocampul gyrus when viewing social threats (e.g. negative facial expressions) compared to individuals without depression symptoms (Foland-Ross & Gotlib, 2012; Stuhrmann, Suslow, & Dannlowski, 2011). Also, the ERP components involved in attention (e.g. P3 and N2) are associated with depression symptoms (Bistricky, Ingram, & Atchley, 2011). These studies suggest that there is considerable overlap of brain structures and timings of neural events between loneliness and the constructs social anxiety/depression. But the extent that these findings can be compared across and within the different neuroimaging techniques is limited.

Another limitation of the study is that a wider age range (18 to 44 years) for the sample was used. It is possible that age may have affected the findings on how the brain of lonely individuals' process threatening stimuli and these effects may be either stronger or weaker in a limited age group. This may be because older lonely adults may be higher on loneliness or experienced loneliness for a longer time compared to younger lonely adults. Future studies could specify certain age groups that examine the processing of threatening stimuli in the brain of lonely people.

In sum, the current research provides additional information on how loneliness impacts the processing of threatening stimuli. For instance, the brain microstates evoked in lonely individuals varied as a function of social threats and non-social threats with a simpler microstate structure (e.g., fewer microstates) evoked by social than non-social threats. In contrast, the microstates evoked in non-lonely individuals by social and non-social threats were similar in number with the early microstates showing striking commonality. The estimated regions of brain activation need to be validated in statistically well-powered fMRI studies (Button et al., 2013), but the present results suggest there were a greater number of evoked brain microstates and a much richer spatial and temporal sequence of regional brain activation than hypothesised and then observed in prior research.

Chapter 7: General Discussion & Overall Conclusions

This final chapter provides a summary of the main findings of each empirical study of the present thesis and discusses these findings within the context of the loneliness literature. Specifically, emphasis of this chapter is placed on the theoretical and practical implications of the research findings of the thesis. Also, the chapter includes a discussion of the impact that these thesis findings will have on loneliness research and provides possible research avenues regarding the next step for loneliness research.

Within the evolutionary loneliness model, Cacioppo and Hawkley (2009) propose that loneliness is associated with a hypervigilance (i.e. higher alertness) to social threats. This is thought to cause attention, memory, and behavioural biases that undermine the opportunity to maintain positive social relationships. Empirical evidence supports this claim across the lifespan, with reports that lonely people see the world as more threatening than non-lonely people (Cacioppo et al., 2000; Qualter & Munn, 2002), remember more negative social information (Duck et al, 1994; Jones & Hebb, 2003; Harris, 2014), report more interpersonal stress than non-lonely people (Doane & Adam, 2010; Harris, 2014), and expect social interactions to be more negative (Cacioppo & Hawkley, 2005; Jones & Hebb, 2003). Thus, from an evolutionary viewpoint, loneliness corresponds to a signal (like hunger or thirst) that an individual needs to act and resolve what is lacking (Cacioppo et al, 2014). In other words, loneliness motivates individuals to repair connections and strengthen social ties, which ensures the survival of genes and contributes to health and well-being (Cacioppo & Hawkley, 2009). Initially, the model of loneliness was developed to provide a link between loneliness and poor health. The authors of the model suggested that the cognitive and behavioural biases associated with feelings of loneliness lead to the activation of neurobiological mechanisms, which increase HPA activation and diminish sleep quality. However, a number of initial cognitive processes are involved in this relationship, and this aspect of the model has received little direct empirical examination in the loneliness literature.

As outlined in chapter 2 of this thesis, the cognitive processes described in Cacioppo and Hawkley’s model have not been examined systematically and five gaps in the research warranted further examination. Firstly, no empirical study had directly examined the hypervigilance to social threat hypothesis of loneliness in an adult sample. To date, only one study has directly examined this using eye-tracker methodology in a child sample (Qualter et al, 2013b: study 3). However, it was not ideal to assume that the pattern of visual attention will be similar across the lifespan (i.e. developmental changes in attention occur with age) without conducting relevant research and further study with adults was warranted. Secondly, no research had investigated the visual attentional biases of lonely adults towards social threat information linked to social rejection or social exclusion. That was because earlier work had shown that lonely adults were more likely to anticipate rejection by others compared to their non-lonely peers (e.g. Jones et al, 1981), and lonely children were more likely to show an over-reaction to rejection vignettes and visual attentional biases to social rejection stimuli (Qualter et al, 2013b). That indicated that there may be a specific type of social threat (possible social rejection) that lonely people were attentive to in the social environment but, again strict, robust examination of this idea was missing from the literature. Thirdly, no research study had examined the visual attention processing of lonely adults to social threat information depicted as emotional information linked to facial expressions. Prior research indicated that individuals reported as having fewer close friendships (not a direct measure of loneliness) were more attentive to emotional vocal tones in a modified stroop task (Gardner et al, 2005), but no research has examined this in lonely people.

Fourthly, in line with the above, no research had attempted to conceptualise social threats for lonely adult in the hypervigilance to social threat hypothesis. As indicated by research, social threats may be conceptualised as a specific bias linked to social rejection and social exclusion or a generalised bias to all social threats (i.e. to negative emotional information).

Lastly, no empirical research had examined the spatial (location) and temporal (time) dynamics of the hypervigilance to social threats hypothesis in loneliness. Specifically no study had investigated how lonely adults' processed social threat information linked to social rejection stimuli in the brain. Previous research suggested that loneliness was associated with a greater activation in the visual cortex in response to unpleasant social pictures compared to unpleasant non-social pictures (Cacioppo et al, 2009), but no study had examined the threat aspect (i.e. social threat versus non-social threat) of the hypothesis.

Summary of studies in the thesis

Study 1 was the first study to directly examine the hypervigilance to social threat hypothesis in lonely adults using eye-tracker methodology. The main focus of that study was to assess the visual attentional biases of lonely adults while viewing real life video footage of social rejection and positive scenes. Findings from that study showed adults scoring in the upper quadrant of loneliness were more likely to have their first fixation on the socially threatening stimuli than non-lonely, more likely to fix their attention (e.g. hypervigilance) on the social threat stimuli initially compared to non-lonely adults, and quickly avoided the social threat stimuli after two seconds in line with non-lonely adults. This suggests that lonely adults showed a visual attentional bias consistent with the hypervigilance to social threat hypothesis. However, Qualter et al (2013b) found a different pattern of attention in children using the same stimuli; children in the upper quadrant of loneliness showed difficulty in disengaging from the social threat stimuli. Both of these attentional biases have been found in the eye-tracking literature. This difference in attention pattern between lonely children and lonely young adults can be explained by cognitive maturation across development.

Studies 2, 3, and 4 were the first set of studies to examine how lonely adults attend to visually presented emotional information and eye-gaze. Study 2 utilised a cognitive paradigm in order to investigate whether lonely adults were hypervigilant to social threats depicted as eye-gaze cues. The findings from study 2 showed that loneliness was not associated with the subjective perception of directed or averted angry faces. Study 3 was the first to examine the processing of emotional information presented simultaneously as four facial expressions (anger, fear, happy and neutral) using eye-tracker methodology. Findings from study 3 showed that loneliness was associated with an increased vigilance to angry faces and neutral faces during the full viewing period. This suggests that lonely adults exhibited a pattern of attentional bias consistent with disengagement difficulties from social threats. Loneliness was not associated with attention to either the happy or fear facial expressions. Study 4 was the first to examine whether lonely adults are hypervigilant to angry faces in a crowd of happy faces using an adaption of the visual search paradigm and eye-tracker methodology. The findings from study 4 showed that loneliness was associated with greater attention to the angry faces in the crowds that were predominantly populated with happy faces (e.g. anger superiority effect). Loneliness was not associated with attention to happy faces in any of the crowd ratios presented. Studies 3 and 4 indicate that lonely adults are more likely to attend to angry facial expressions (i.e. social threats) compared to other emotional information.

Study 5 extends the research work from study 1 and examined whether loneliness was associated with hypervigilance to social threats linked to social rejection and social exclusion using static images. Study 5 investigated this notion by simultaneously presenting four visual images (social rejection, physical threat, social positive and neutral), while eye responses were recorded using eye-tracker methodology. Findings from study 5 suggest that loneliness was associated with increased vigilance to the social rejection stimuli during the full viewing period. These findings are consistent with the attentional pattern of disengagement difficulties from social rejection stimuli. Loneliness was not associated with attention to images of physical threat, social positive and neutral scenes. This suggests that lonely adults are on high alert for specific social threats that are linked to social rejection and social exclusion.

Studies 2 to 5 were also the first set of studies to examine the social-cognitive associations of loneliness while controlling for social anxiety and depression. As outlined in chapter 4, this is important because the construct of loneliness overlaps with the related constructs of social anxiety and depression, and the previous literature shows an overlap of cognitive biases with the construct of social anxiety and depression. When controlling for social anxiety and depression in the analyses of studies 2 to 5, some of the effects found with the construct of loneliness (without controlling for social anxiety and depression) for these studies changed. When controlling for social anxiety and depression in the analyses, study 2 showed that adults scoring higher on loneliness were less likely to subjectively perceive directed eye-gaze of angry faces as looking at them. This finding could either suggest vigilant or avoidance of social cues. Findings from study 3 indicated that once controlling for social anxiety and depression, loneliness was not associated with increased attention to angry faces or neutral faces. Consistent with previous eye-tracking literature, further analyses indicated that the effect found for the angry faces was due to the construct of social anxiety, and the effect for the neutral faces was due to the construct of depression. Also, results showed that loneliness was not associated with happy or fearful faces. Results for study 4 controlling for social anxiety and depression showed that loneliness was not associated with increased attention to angry faces in the crowd types that were populated with happy faces. Further analyses indicated that the effect for the angry faces in the crowd types was due to the construct of depression. For studies 3 and 4, these findings suggest that loneliness was not associated with hypervigilance to social threats depicted as angry faces, while controlling for social anxiety and depression in the analyses.

When controlling for social anxiety and depression, study 5 showed that loneliness was associated with increased attention (hypervigilance) to social threat linked to social rejection and social exclusion stimuli. This effect remained unchanged when controlling for social anxiety and depression suggesting the effect was due to loneliness. Findings also showed that loneliness was associated with a decreased attention to the neutral images. This suggests that loneliness was associated with a hypervigilance/disengagement difficulty response pattern to the social threat images, and with an avoidance response pattern to the neutral images. In addition, loneliness was not associated with attention to the social positive or physical threat images. However, in this thesis, study 1 and the neuroimaging data from study 6 did not control for the related constructs of social anxiety and depression. The theoretical and practical implications (below) are discussed in line with the findings of loneliness only and not with the findings controlling for social anxiety and depression. As discussed earlier in this thesis, controlling for these related constructs is important because the shared features of loneliness with social anxiety and depression may drive different effects in the results presented. But, the practical implications for interventions should be based on the findings from loneliness only because researchers are not able to remove the variance due to the related constructs of social anxiety and depression from people who are lonely in everyday life.

Study 6 extended the research work from study 1 and study 5 of this thesis and focused on the notion that hypervigilance to social threats was a specialised bias to social rejection, instead of a generalised bias to all social threats. Study 6 was the first study to examine how social threats linked to rejection (vs non-social threats) were processed in the brain of lonely adults compared to non-lonely adults. The study used high-density electrical neuroimaging (EEG, CENA and brain source localisation wMNE) and a behavioural task including social threat and non-social threat images. Findings from study 6 showed that lonely and non-lonely adults did not differ in their responses on the behavioural task, suggesting that hypervigilance to social threat may occur at an implicit level. The results for the behavioural task did not change when social anxiety and depression were controlled.

Neuroimaging data indicated that lonely adults (~116 ms) were quicker to differentiate between social threats and non-social threats when compared to non-lonely adults (~252 ms). The brain regions estimated in lonely adults were those brain regions involved in attention and preparation for threat. In addition, lonely adults processed social threats and non-social threats in a different manner, with a different number and duration of each microstate. The simple effects of lonely adults showed a microstate structure with a total of five microstates for the social threat condition, and a total of seven microstates for the non-social threat condition. This suggests that the stages of processing social threats were slower in duration than the processing of non-social threats (i.e. biological threat). In contrast, simple effect of non-lonely adults showed a microstate structure with a total of four microstates for the social threat condition, and a total of four microstates for the non-social threat condition. This implies that the stages of processing were similar for social threat and non-social threat images.

Theoretical implications of research

The studies in this thesis systematically examined the hypervigilance to social threat hypothesis in lonely adults. This initial process forms part of Cacioppo and Hawkley’s (2009) model, which assumes that lonely individuals are on high alert for social threats that leads to cognitive biases. Consistent with previous research, studies 1, 3, 4, 5, and 6 found supporting evidence that shows lonely adults attend more to negative social information in the social world (e.g. Cacioppo et al, 2009; Egidi et al, 2008).

Specifically, studies 1, 5, and 6 found supporting evidence for the notion that loneliness is associated with hypervigilance to social threats linked to social rejection and social exclusion. This supports prior empirical research that shows that lonely people are more likely to anticipate rejection by others compared to their non-lonely peers (Jones et al, 1981; Jones & Hebb, 2003), but lonely people are not necessarily rejected by others (London et al, 2007; Qualter & Munn, 2005). In childhood, loneliness is associated with the perception and over-reaction to rejection vignettes (Qualter et al, 2013b). This suggests that there may be a specific type of social threat (possible social rejection) that lonely people are attentive to in the social environment and findings from study 1, 5, and 6 support that notion. Also, findings from studies 1, 5, and 6 are consistent with Kemeny's social threat conceptual model (2009). That model suggests that threats to one's social status such as social devaluation, discrimination, or rejection can have negative impacts on maintaining social connections for humans. This thesis builds on the work from Kemeny's model (2009) and expands their definition of social threat to the loneliness literature. That is because Cacioppo and Hawkley (2009) did not explicitly detail what a social threat was and what the authors were referring to in their model.

In addition, studies 1, 5, and 6 showed evidence that hypervigilance to social threats in loneliness is reflected in visual attentional biases to social threat stimuli, as proposed by Cacioppo and Hawkley in their model. Study 1 and study 5 indicated different visual attention processing styles for lonely adults using eye-tracker methodology, but both of these patterns are consistently found in eye-tracker research (for review see Armstrong & Olatunji, 2012). Findings from study 1 indicated a hypervigilance-avoidance pattern of processing of video footage showing social threat, while study 5 showed a difficulty in disengaging from static images of social threat. One possible explanation for the different attentional biases to social threat stimuli is that not all lonely adults attend to social threat in the same way. It is possible that adults in the sample of study 1 could have felt lonely for prolonged periods of time (chronic), thus they showed an initial hypervigilance response to identify the social threat information and then they showed a practised avoidance strategy to avoid the social threat stimuli. Chronically lonely adults may use practised avoidance strategies because they have had longer exposure times to these stimuli in their lives. In contrast, adults in the sample of study 5 could have felt lonely for a shorter period of time (transient) and thus find it difficult to disengage from social threat stimuli. This is because transiently lonely adults have not been exposed to those types of stimuli previously, so they are not aware on how to response. Alternatively, the range of loneliness scores differed across studies 1 and 5 and this might explain why some lonely adults showed a hypervigilance-avoidant pattern of processing, while other lonely adults showed difficulty in disengaging from social threat stimuli. Findings from study 5 in which lonely adults showed disengagement difficulties from social threat stimuli are consistent with eye-tracker research in lonely children (Qualter et al, 2013b). That study indicated that lonely children had difficulty in disengaging from real life video footage of social threat, with the authors arguing the role of this attentional bias in the maintenance of loneliness, possibly by ruminating on negativity. Using neuroimaging, study 6 provided evidence that lonely adults are hypervigilant to social threats in the way they show implicit vigilance to social threat stimuli and elicit brain regions that are involved in attention and preparation of threat in the earlier microstates. All of these studies indicate that loneliness is associated with hypervigilance to social threats that extend beyond negative cognitive appraisals of the social world to visual attention deployment and processing in the brain.

Study 2 examined the hypervigilance to social threat hypothesis of loneliness, but failed to find supporting evidence that loneliness was related to the processing of basic social cues (i.e. eye-gaze and emotion). These findings did not support the results of the study conducted by Kunai et al (2012), which found loneliness was associated with a difficulty in discriminating the eye-gaze of others. The findings of study 2 suggest that loneliness is not related to the hypervigilance or avoidance of eye-gaze when asked to subjectively respond on an explicit level. This difference in results between study 2 and Kunai et al's (2012) study could be because study 2 used a more specific perceptual task, while Kunai et al used a more general discrimination task.

Findings from studies 3 and 4 show that loneliness is associated with hypervigilance to social threats depicted as angry facial expressions, even in a group context. Results of these studies showed supporting evidence for Cacioppo and Hawkley's proposal and found that social threats may be a generalised threat as well as a specialised threat for lonely adults. However, findings did not support the Social Monitoring System (SMS) proposed by

Gardner et al (2000). The SMS suggest that lonely people extensively monitor the social environment (I.e. hypervigilance) for both positive and negative social cues in an attempt to encourage behaviours that would promote social opportunities. Findings from studies in this thesis show that lonely adults do not extensively process or attend to positive social cues such as happy facial expressions (studies 3 and 4), socially positive IAPS images (study 5), and socially positive real-life video footage (study 1). These findings were not consistent with previous studies that have examined the SMS. For instance, lonely adults remembered more social positive and social negative events after reading diary extracts of others (Gardner et al, 2005). Also, adults reporting fewer close friendships showed greater attention to emotional vocal tones (Gardner et al, 2005). The findings of the studies included in this thesis did not find evidence for visual attentional biases of positive social cues. This may be because lonely adults are more focussed on self-preservation cues.

The findings of the studies in this thesis support the notion that loneliness is an aversive signal that puts individual on high alert (i.e. hypervigilance) for social threats in an attempt to reduce social pain (Cacioppo et al, 2014). However, these studies did not examine whether this hypervigilance to social threat response is an adaptive or a maladaptive response. Some theorists in the field (e.g. Cacioppo et al, 2014; Qualter et al, 2015) suggest that hypervigilance to social threat response is adaptive in nature because it highlights to individuals that their social connections are at risk and motivates them to reconnect with others. While for some lonely individuals, this hypervigilance to social threat response is thought to be a maladaptive response that leads to prolonged loneliness by those individuals getting stuck in the loneliness model, which prevents them from making social connections. Cacioppo and Hawkley (2009) propose that hypervigilance to social threats occurs at an implicit (automatic) level rather than at an explicit (conscious) level. Findings from studies presented in this thesis offer some insights into this. Studies 1, 3, 4, 5, and neuroimaging data from study 6 support the view that hypervigilance to social threats occurs at an implicit automatic (unconscious) level. But, findings from the behavioural task and subjective ratings of social threat stimuli (study 6) failed to find evidence that loneliness is associated with hypervigilance to social threats at an explicit (conscious) level.

Implications for interventions from thesis findings

The findings of this thesis suggest that lonely adults are hypervigilant to social threats that are visually presented during experimental conditions. Those results indicate interventions, such as attention retraining and priming of social acceptance cues, may be effective in helping lonely adults reduce their overall levels of loneliness.

Findings from studies 1 and 6 imply that lonely adults are quicker to detect social threats in the environment (i.e. they are on high alert). Those findings propose that interventions strategies that prime social acceptance cues could be considered because they may provide lonely adults with skills to focus their attention on positive social aspects of the social scene, instead of focussing on social threats (see Qualter et al, 2015). For instance, Lucas, Knowles, Gardner, Molden and Jefferies (2010) reported that subtly priming lonely participants to social acceptance cues by promoting a focussed mind-set was successful in motivating behaviours and thoughts involved in affiliation. In line with these findings, an intervention can be proposed in which lonely adults are primed to social acceptance cues by showing them socially positive pictures. This would help them to attend to positive social features in the social environment. The research findings also indirectly indicate that skills could be taught to lonely adults on how to attempt reconnection with other people, which will increase the likelihood of social opportunities. For example, interventions used for older adults could be adapted for lonely adults. Those interventions include weekly group sessions aimed to improve social skills (Fokkema & van Tilburg, 2007), and teach skills at taking initiative in making new friends, investing in friendships and having a positive frame of mind (Kremers, Steverink, Albersnagel & Slaets, 2006). The latter suggestion is important because the loneliness signal is thought to be an adaptive response that aims to promote reconnections with others, so the latter approach may be effective for all lonely people (i.e. transiently lonely or prolonged feelings of loneliness).

Findings from studies 3 and 4 showed that lonely adults are hypervigilant to social threats depicted as angry facial expressions. Interventions that focus on teaching lonely adults to relocate their attention from negative emotions in the social world towards positive emotions may be effective. For instance, the attention bias modification intervention has had success for individuals with anxiety and depressive symptomology. That intervention attempts to train an individual's attention away from disorder-related stimuli with the use of dot-probe, visual cueing and visual search tasks (Magoase, David & Koster, 2014). Also, mental imagery and visualising social scenes may be effective tools that lonely adults could use. For instance, concentrative meditation is a strategy that teaches people to focus attention on a single aspect, whilst ignoring other aspects (Chambers, Gullone & Allen, 2009).

Findings from study 5 suggest that attention retraining may be effective because the findings show that lonely adults fail to disengage from social threats. Disengagement difficulties from social threats are argued to be involved in the maintenance of disorders (i.e. social anxiety and depression) and loneliness in children because it leads to rumination of negativity. Therefore, interventions could teach lonely adults what to focus on in the social environment, so they gather useful information to change behaviours to promote reconnection. The two interventions mentioned above (attention bias modification and concentrative meditation) may be effective for lonely adults because they retrain attention away from social threat stimuli and teaches them to focus their attention on the positive stimuli.

In the study samples, a distinction on whether lonely individuals were transiently lonely or chronically lonely was not made. It is possible that the samples used in the studies included (1) individuals that felt lonely for a short period of time as some of the university students had moved away from home, but were still high on levels of loneliness and (2) included individuals that felt lonely for prolonged periods of time. The different pattern of attentional biases found for lonely adults for study 1 (hypervigilance and avoidance) and study 5 (disengagements difficulties) may be the outcome of the fact that those individuals in study 1 were feeling lonely for prolonged periods of time while those individuals in study 5 were transiently lonely or vice versa. These findings propose that different strategies may need to be put in place for those adults that are transiently and chronically lonely. For instance, transiently lonely adults may need to develop skills to disengage from social threats in the social environment, while chronically lonely adults develop skills on how to use this hypervigilance in a positive way to develop social opportunities. Therefore, future research could include an element of longitudinal methods in their study designs.

The interventions proposed above are focussed on addressing the attentional bias of lonely adults to social threat in the social world. In support of this, a number of intervention strategies that address the maladaptive social cognitions were found to be most effective in a meta-analysis review conducted by Masi et al (2011). Specifically, the authors found that interventions such as cognitive behavioural therapy targeting the negative thoughts and attitudes associated with loneliness were more effective at reducing levels of loneliness in adults and older adults. In contrast to this, strategies that improve social skills, increase social opportunities, and enhance social support were shown to be less effective because the latter two strategies are thought to target social isolation instead of loneliness.

Elaboration of Cacioppo and Hawkley's model

Findings from the studies in this thesis propose that elaborations may be required for Cacioppo and Hawkley's model of loneliness. Studies 1, 5, and 6 provide consistent evidence that lonely adults are hypervigilance to social threats that are linked to specific threats of social rejection or social exclusion. Therefore, these findings imply that the hypervigilance to social threat hypothesis may need to be redefined as the hypervigilance to social rejection hypothesis. However, some evidence from studies 3 and 4 support the notion that lonely adults are hypervigilance to social threats depicted as angry emotions on facial expressions. This suggests that hypervigilance to social threat hypothesis for lonely adults may be both a specialised and generalised bias to social threats. Specifically, the thesis findings have identified what a social threat looks like in the model for lonely adults (social rejection and angry faces), which was previously missing from the literature. In addition, the findings of this thesis consistently show that hypervigilance and attentional bias occur towards visually presented social threat stimuli during experimental conditions. Thus, the implicit hypervigilance to social threat should incorporate the mode of presentation (i.e. visual) into the hypothesis. The elaborations to the model mentioned above need to be supported by work using longitudinal methods because studies in this thesis are based on cross-sectional studies.

Strengths of the thesis

The research included in this thesis makes important contributions to the field of loneliness and cognition. Firstly, the thesis provides direct supporting evidence that loneliness is associated with an implicit hypervigilance to social threat, which is reflected in visual attentional biases. This was important to examine because Cacioppo and Hawkley propose that these initial cognitive processes lead onto behavioural changes and cause negative implications for physical health in some lonely adults. Secondly, the research findings in this thesis indicate that attentional biases to social threats can be defined as social rejection and negative emotions for lonely adults. This is important because intervention work to reduce loneliness could focus on these social threats that have been identified by research.

Overall, the methodologies used to examine the hypervigilance to social threat hypothesis were very effective in addressing the research questions. Studies 1, 3, 4, and 5 examined the visual attention biases of lonely adults using eye-tracker methodology. Study 6 used high density neuroimaging that incorporated both EEG methods to identify specific timings of neural events, and source localisation techniques to identify specific brain regions activated when viewing social threat images. The use of different methodologies and experimental designs in research mean that a clearer picture is known about the patterns of social information processes associated with loneliness.

Limitations of the thesis

The individual limitations of each empirical study are discussed in the relevant chapters. The limitations included this section are discussed for the whole thesis. The empirical studies conducted in this thesis were all of cross-sectional design (i.e. hypervigilance and loneliness measures were taken at one-time point only) and did not include longitudinal methods (i.e. hypervigilance and loneliness measures were not taken at different points over time). The focus of the current thesis was on the examination of whether loneliness was associated with hypervigilance to social threats in a general way. Now that those original proposals have been supported by research, it is important for researchers to examine how these attentional biases are associated with loneliness over time. Such an examination extends Cacioppo and Hawkley’s model, so that a link can be made between attentional biases and prolonged loneliness. Researchers have begun to examine how cognitive biases are associated with loneliness over time in adults (e.g. Yang, in prep).

The samples used in the current studies were limited to an undergraduate sample of young adults/adults. Future research could look at the attentional biases over the lifespan to examine whether there are differences in information processing of social threat stimuli. Studies 2 to 6 of this thesis could be replicated in children and older adults who feel lonely. Such an examination would provide more of a developmental perspective to the loneliness model, which is currently missing from the loneliness literature with the exception of a few studies (e.g. Harris, 2014; Qualter et al, 2013b). This is important because loneliness occurs over the lifespan (see Qualter et al, 2015) and also the pattern of cognitive biases may be exhibited differently across development, so appropriate interventions can be designed. Based on previous research, researchers may speculate what they expect to find for lonely children and lonely older adults. Using eye-tracker methods, lonely children are likely to show disengagement difficulties of social threat to static images, while lonely older adults may show both attentional processes (hypervigilance-avoidance and disengagement difficulties) depending on their level of loneliness. Using brain imaging methods, lonely children may show greater activation in the amygdala (fear circuitry of the brain) to social threat, while lonely older adults may show initial activation in the amygdala followed by activation in regions involved in social cognition.

As mentioned in one of the sections above, the studies of this thesis did not differentiate between adults in the samples who felt lonely for a short period of time (transient) from those who felt lonely for prolonged periods of time (chronic). Future research should make this distinction because the presentation of hypervigilance/attentional biases found may be different for transiently and chronically lonely adults. Future research could examine this by conducting longitudinal studies to examine this over time.

The empirical studies in this thesis did not focus on the examination of gender differences. This is because the aversive signal of loneliness is thought to evolve in a similar manner for males and females (Heinrich & Gullone, 2006) and differences between genders are not expected. In addition, prior research examining loneliness and cognitive biases have not looked at gender differences (Heinrich & Gullone, 2006), with the exception of study 1 that reported no gender differences in loneliness for visual processing. However, there could be gender differences when examining loneliness and cognitive biases. Therefore, any future research should consistently report the role of gender on cognitive biases in studies measuring loneliness to rule out the effects of gender. The focus of the studies in the thesis was on visually presented stimuli because the thesis aimed to examine whether lonely adults were on the look out for social threats. However, further studies could examine whether biases (i.e. hypervigilance) are also found in auditory information and in written format. Across the studies, it is possible that the loneliness questionnaire given before the experimental study primed all participants to be more susceptible to social threatening information. Future work could counterbalance the completion of the questionnaires and experimental study.

The studies of this thesis used different cut-off scores to define extreme loneliness and this could have affected the results. Therefore, further work is needed in the field in order to establish well-defined cut-off scores for loneliness and extreme loneliness. That work is important because there are no known cut-off scores in the loneliness literature that defines whether an individual is lonely or has extreme levels of loneliness. This is different to other constructs such as depression and anxiety.

The lonely adults in the empirical studies may have been high on levels of rejection sensitivity (e.g. those who readily expect and perceive rejection from others). Given that the rejection sensitivity model (Downey and Feldman, 1996) proposes that individuals with high levels of rejection sensitivity scores are more likely to focus on social exclusion cues in the social environment, it is possible that this may have produced some of the loneliness effects. Thus, future work could control for the construct of rejection sensitivity in the analyses.

Finally, the choice of controlling for the related constructs of social anxiety and depression may have eliminated variance that was otherwise attributed to the construct of loneliness. Future work could present the results in line with the presentations of results in chapter 4 stating the (1) effect of loneliness, and the (2) effect of loneliness whilst controlling for social anxiety and depression. So, researchers can distinguish between the effects clearly.

Impact of research findings and next step for loneliness research

The findings of this thesis are important because they indicate that loneliness is associated with hypervigilance to social threats in adults. However, the research undertaken in this thesis proposes further research questions that need to be addressed in the loneliness field. Now that considerable research has equivocally found that lonely adults are hypervigilance to social threats that leads to attentional biases, the next step is to focus the examination on whether these attentional biases cause behavioural deficiencies (i.e. social withdrawal), and whether this is the case for lonely adults or not. This is important because these biases are thought to undermine the opportunity to maintain social relationships. That work would require the use of longitudinal design methods and observational methods.

As much of the research described in this thesis was conducted under controlled laboratory settings, it is unclear whether these findings will be replicated in naturalistic settings for lonely adults. Therefore, future studies could be conducted in real life situations, where cognitions and behaviours are monitored over time. It can be expected that lonely adults may show a hypervigilance response to social threats in the social world.

In addition, research described in this thesis focussed on a specific age range of young adults/adults. Cognitive biases and pattern of information processing may change or differ across development. This is important to look at because prior eye-tracker research has found that different patterns of information processing for social threat stimuli do exist for lonely children and lonely adults. So, it is not ideal to assume that the same patterns will occur for lonely children, lonely adults and lonely older adults. Therefore, the next step is to examine whether and how cognitions develop over the lifespan for lonely people. Such an examination would entail a replication of the studies within this thesis to a sample of lonely children and lonely older adults from different groups.

Finally, the research findings of this thesis suggest that lonely adults conceptualise social threats linked to rejection and angry facial expressions. However, the conceptualisation of social threats might differ across the lifespan. For example, a lonely child may construe social threats as signs of peer rejection and all negative facial expressions as such, whilst a lonely older adult may construe social threats to rejection in intimate relationships only. Therefore, further studies are needed to understand how social threats differ for lonely children, lonely adults and lonely older adults. That work could be incorporated into a wider study examining differences in cognitions across the lifespan.

Conclusions

Overall, the findings of this thesis make an original contribution to the field of loneliness by expanding previous research and examining the initial cognitive processes of Cacioppo and Hawkley's (2009) loneliness model. Specifically, the thesis findings indicate that lonely adults are hypervigilant to social threats depicted as angry facial expressions and social rejection stimuli, during experimental conditions. In addition, the findings of the thesis can be used to inform ideas for future academic and intervention work in the loneliness field.

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Appendix A: Evidence of Ethical Processes

Study 1: Ethical Approval

23 August 2010

Pamela Qualter
Psychology Department
University of Central Lancashire

Dear Pam,

Psychology Department Ethics Committee
Unique Reference Number: **PSY0607024_amendment_Aug_10**

The Psychology Department Ethics Committee has approved your proposed amendment to your application 'Social engagement, emotional intelligence and loneliness among school-children: Phase I and 2'. The requested amendment included the investigation of social threat with university students, using the eye-tracker methodology detailed in the earlier ethics proposal.
Yours sincerely

Mike Eslea
Chair
Psychology Department Ethics Committee

Study 2: Ethical Approval

20 February 2012

Dr Pamela Qualter / Munirah Bangee
School of Psychology
University of Central Lancashire

Dear Pamela / Munirah

Re: PSYSOC Ethics Committee Application
Unique Reference Number: PSYSOC 015

The PSYSOC ethics committee has granted approval of your proposal application '**Loneliness and hyper-vigilance to social threat**'. However, please note that participants from within Psychology cannot get "course credit". Make sure all materials refer to "participation points" instead.
Please note that approval is granted up to the end of project date or for 5 years, whichever is the longer. This is on the assumption that the project does not significantly change, in which case, you should check whether further ethical clearance is required

We shall e-mail you a copy of the end-of-project report form to complete within a month of the anticipated date of project completion you specified on your application form. This should be completed, within 3 months, to complete the ethics governance procedures or, alternatively, an amended end-of-project date forwarded to roffice@uclan.ac.uk quoting your unique reference number.

Yours sincerely

Mike Eslea
Chair
PSYSOC Ethics Committee

Studies 3, 4 & 5: Ethical Approval

3 July 2012

Dr Pamela Qualter / Munirah Bangee
School of Psychology
University of Central Lancashire

Dear Pamela / Munirah

Re: PSYSOC Ethics Committee Application
Unique Reference Number: **PSYSOC 015 (2nd phase)**

The PSYSOC ethics committee has granted approval of your proposal application '**Loneliness and hyper-vigilance to social threat – 2nd phase**'. However, please note that participants from within Psychology cannot get "course credit". Make sure all materials refer to "participation points" instead.
Please note that approval is granted up to the end of project date or for 5 years, whichever is the longer. This is on the assumption that the project does not significantly change, in which case, you should check whether further ethical clearance is required

We shall e-mail you a copy of the end-of-project report form to complete within a month of the anticipated date of project completion you specified on your application form. This should be completed, within 3 months, to complete the ethics governance procedures or, alternatively, an amended end-of-project date forwarded to roffice@uclan.ac.uk quoting your unique reference number.

Yours sincerely

Mike Eslea
Chair
PSYSOC Ethics Committee

Study 6: Ethical Approval for rating the stimuli

15 August 2013

Pamela Qualter / Munirah Bangee
School of Psychology
University of Central Lancashire

Dear Pamela / Munirah

Re: PSYSOC Ethics Committee Application
Unique Reference Number: **PSYSOC 015_3rd phase**

The PSYSOC ethics committee has granted approval of your proposal application '**Loneliness and Hyper-vigilance to social threat: the rating of social stimuli**'.
Please note that approval is granted up to the end of project date or for 5 years, whichever is the longer. This is on the assumption that the project does not significantly change, in which case, you should check whether further ethical clearance is required

We shall e-mail you a copy of the end-of-project report form to complete within a month of the anticipated date of project completion you specified on your application form. This should be completed, within 3 months, to complete the ethics governance procedures or, alternatively, an amended end-of-project date forwarded to roffice@uclan.ac.uk quoting your unique reference number.

Yours sincerely

Cath Sullivan
Chair
PSYSOC Ethics Committee

Study 6: CITI Approval

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI)
RESPONSIBLE CONDUCT OF RESEARCH CURRICULUM COMPLETION REPORT
Printed on 09/11/2013

LEARNER	Munirah Bangee (ID: 3524387)
DEPARTMENT	Psychology
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INSTITUTION	University of Chicago
EXPIRATION DATE	

SOCIAL AND BEHAVIORAL RESPONSIBLE CONDUCT OF RESEARCH COURSE : This course is for investigators, staff and students with an interest or focus in Social and Behavioral research. This course contains text, embedded case studies AND quizzes.

COURSE/STAGE:	Basic Course/1
PASSED ON:	09/11/2013
REFERENCE ID:	10593190

REQUIRED MODULES	DATE COMPLETED	SCORE
Introduction to the Responsible Conduct of Research	09/10/13	No Quiz
Research Misconduct (RCR-SBE)	09/10/13	5/5 (100%)
Data Management (RCR-SBE)	09/10/13	5/5 (100%)
Authorship (RCR-SBE)	09/10/13	5/5 (100%)
Peer Review (RCR-SBE)	09/11/13	5/5 (100%)
Mentor and Trainee Responsibilities 0-1466	09/11/13	6/6 (100%)
Conflicts of Interest (RCR-SBE)	09/11/13	5/6 (83%)
Collaborative Research (RCR-SBE)	09/11/13	5/5 (100%)
The CITI RCR Course Completion Page	09/11/13	No Quiz

For this Completion Report to be valid, the learner listed above must be affiliated with a CITI Program participating institution or be a paid Independent Learner. Falsified information and unauthorized use of the CITI Progam course site is unethical, and may be considered research misconduct by your institution.

Paul Braunschweiger Ph.D.
Professor, University of Miami
Director Office of Research Education
CITI Program Course Coordinator

Study 6: Ethical Approval

AURA IRB | THE UNIVERSITY OF CHICAGO

SBS-IRB
5835 South Kimbark Avenue - Judd Hall 336
Chicago, IL 60637
SBS IRB website: http://sbsirb.uchicago.edu/

Notification of Expedited Approval

Date of Letter: 9/23/2013
Protocol Number/Submission Link: IRB13-1076
Type of Submission: New Study
Status: **Approved**
Principal Investigator: Stephanie Cacioppo
Protocol Title: A comparison of responses to social threat in lonely individuals and physical threat in phobic individuals
Risk Level: Minimal Risk
Consent Type: Written Consent Obtained
Waiver of Documentation of Consent
Vulnerable Populations: None - Healthy Adults
Funding: Internally Funded

Protocol Version: Version #1
Stamped Documents: Oral Consent.docx.pdf
Approval Date: 9/20/2013

The above-referenced study was approved by the IRB. The expiration date of this study is 9/19/2014.

Any modifications to this research protocol or materials pertaining to the study must be submitted for review and granted IRB approval prior to implementation.

The IRB maintains ongoing review of all projects involving human subjects or analysis of human subjects' data at continuing intervals.

All research-related adverse events or unanticipated problems occurring in the course of the protocol must be reported to the IRB within ten (10) days following the event.

The investigator(s) agree to abide by all University of Chicago research policies including, but not limited to, the policies on responsible conduct in research, conflict of interest and maintenance of project data/materials as required.

Stamped approved documents associated with this study can be found in the study workspace, by following the Submission Link above.

If you need assistance, please contact the IRB from the submission workspace by clicking the "Send Email to IRB Team" activity.

Please refer to your IRB's current policy and procedure manual available at: http://humansubjects.uchicago.edu/.

Appendix B: List of stimuli used in the thesis

Study 3 – KDEF Database

Gender of face (M/F) with emotions afraid (AFS), angry (ANS), happy (HAS), neutral (NES)

AF01 (AFS, ANS HAS, NES)

AF03

AF05

AF09

AF15

AF19

AF20

AF21

AF24

AF26

AF29

AF32

AM01

AM02

AM03

AM04

AM05

AM07

AM11

AM21

AM22

AM25

AM29

Study 4 – KDEF Database

AM01 (ANS, HAS)

AM02

AM03

AM04

AM05

AM07

AM08

AM10

AM11

AM17

AM21

AM22

AM23

AM25

AM26

AM29

Study 5 – IAPS Database & Non-IAPS stimuli (denoted with *)

Social threat

2272

2301

2345.1

2387

2900

9041

Ignoring_1*

Ignoring_2*

Ignoring_3*

Ignoring_4*

Ignoring_5*

Ignoring_6*

Lonely_1*

Lonely_2*

Lonely_3*

Lonely_4*

Peer Rejection_1*

Peer Rejection_2*

Peer Rejection_3*

Peer Rejection_4*

Rejection_1*

Rejection_2*

Rejection_3*

Rejection_4*

Physical threat

1019

2205

2691

2718

6242

6312

6571

6610

6800

6832

7521

9220

9403

9415

9419

9424

9427

9530

9622

9623

9630

9830

9909

9926

Social Positive

2151

2156

2158

2217

2222

2274

2299

2311

2312

2340

2341

2342

2345

2347

2358

2360

2391

2530

2560

2598

4617

4628

8380

8497

Neutral

5201

5202

5210

5215

5250

5593

5594

5631

5665

5711

5720

5725

5760

5781

5814

5820

5825

5870

5891

5982

5990

7492

7530

7580

Study 6 – IAPS Database & Non-IAPS stimuli (denoted with *)

Social threat

2900

9041

Ignoring_4*

Peer rejection_2*

Peer rejection_4*

Rejection_2*

Rejection_3*

Non-social threat

1019

1033

1051

1090

1110

1111

1113

Social non-threat

2579

Crowd_1*

Crowd_2*

Crowd_3*

Line_1*

Market_1*

Walking_1*

Non-social non-threat

5711

5720

7001

7004

7080

7090

7175

Appendix C – Published Paper

Bangee, M., Harris, R. A., Bridges, N., Rotenberg, K. J., & Qualter, P. (2014). Loneliness and attention to social threat in young adults: Findings from an eye tracker study. *Personality and Individual Differences*, *63*, 16-23.

Cacioppo and Hawkley (2009) have hypothesized that lonely people are hyper-vigilant to social threat, with earlier work (Jones & Carver, 1991) linking this bias specifically to threats of social rejection or social exclusion. The current study examined this hypothesis in eighty-five young adults (mean age = 18.22; SD = 0.46; 17-19 years in age) using eye-tracking methodology, which entailed recording their visual attention to social rejecting information. We found a quadratic relation between the participants' loneliness, as assessed by the revised UCLA loneliness scale, and their visual attention to social threat immediately after presentation (2 seconds). In support of Cacioppo and Hawkley's (2009) hypothesis, it was found that young adults in the upper quartile range of loneliness exhibited visual vigilance of socially threatening stimuli compared to other participants. There was no relation between loneliness and visual attention to socially threatening stimuli across an extended subsequent period of time. Implications for intervention are considered.

Keywords: loneliness; hyper-vigilance; social threat; rejection; eye-tracker; attentional bias; attention.

1. Introduction

Cacioppo & Hawkley's model of loneliness (2009) proposes that loneliness is associated with hyper-vigilance to social threat. This could mean that lonely people in their everyday lives (1) fail to make accurate appraisals of social events, such that they misinterpret social events negatively, but also (2) that they have visual attention biases, such that they are 'on the look out' for negative social events so that they can avoid them and protect themselves against psychological pain. Empirical research, thus far, has focused on the first of these two possibilities, but there is a major gap in our knowledge regarding whether lonely adults show visual attention biases to social threat information. The current study directly assesses whether there are differences between lonely and non-lonely adults in the way they attend to social threatening stimuli using eye-tracker methodology.

1.1. Loneliness and attention to social threat

Loneliness is the feeling of distress caused by an individuals' *perceived* lack of fulfilling social relationships (Peplau & Perlman, 1982); the quality, and not the quantity, of social relationships is important in loneliness. Loneliness is a prevalent problem among adults, with recent statistics showing that 1 in 20 adults report feeling completely lonely (Randall, 2012). Loneliness has been implicated in poor mental and physical health in adults (Hawkley, Thisted, Masi, & Cacioppo, 2010), and has been known to cause significant distress and/or intensify mental disorders or conditions, such as depression (Heinrich & Gullone, 2006).

The model of loneliness proposed by Cacioppo & Hawkley (2009) sees lonely people as hyper-vigilant to social threats in the environment; being lonely influences how people perceive their social world, such that they are more likely to remember negative social events, hold negative social expectations, and attend more to information that is socially threatening than non-lonely individuals. Specifically, past research suggests that lonely people are focused on issues of rejection and social exclusion (Jones, Freemon & Goswick, 1981; Jones & Carver, 1991; Sloan & Solano, 1984). This means that social threat for lonely people may be conceptualized as threats that are linked to social rejection or social exclusion.

In support of Cacioppo & Hawkley's model, evidence shows that lonely people use threat-related cognitions to explain their social world. For example, lonely adults report feeling more threatened in social situations and worry that others will ignore or reject them (Cacioppo et al., 2000; Jones et al., 1981); they also report higher levels of interpersonal stress than non-lonely people (Doane & Adam, 2010). In addition, lonely individuals more often blame themselves when explaining the causes of social exclusion compared to non-lonely people (Qualter & Munn, 2002; Solano, 1987).

Interestingly, whilst lonely people have a bias to use threat-related cognitions, these do not match their social experience. Empirical evidence suggests that lonely people perceive or anticipate rejection, but they are not necessarily rejected by others (Jones et al., 1981; London, Downey, Bonica &

Paltin, 2007; Qualter & Munn, 2005).

Research also shows attention and memory biases in lonely people. Lonely adults show greater recall for social events compared to non-lonely people (Gardner, Pickett, Jefferis, & Knowles, 2005), suggesting that social events are particularly salient to them. However, in a classic Stroop test, negative social words (e.g., rejected, alone, disliked) created greater interference for lonely than non-lonely adults (Egidi, Shintel, Nusbaum, & Cacioppo, 2008); there were no differences on positive social words. This finding is consistent with Cacioppo and Hawkley's (2009) theory because it suggests that loneliness intensifies feelings of potential threat: loneliness appears to prime people to look for negative social events in the environment. Further support comes directly from Cacioppo, Norris, Decety, Monteleone and Nusbaum (2009) who showed loneliness increases attention to negative social information. They report that lonely people had fewer neural responses to pleasant social stimuli, with heightened neural activation in the visual cortex during the viewing of unpleasant social pictures, thus, indicating lonely adults have greater visual attention to these stimuli.

Although these latter studies provide important information about attentional biases for social threat among lonely people, the assessment is incomplete because it does not look at visual processing of social threat information. There is a necessity for research investigating attentional biases in loneliness using eye-tracker technology to complete the picture of cognitive biases of lonely people (Goossens, 2012); we need further examination of whether the hyper-vigilance for social threat hypothesis for loneliness extends beyond negative cognitive appraisals of the social world to visual attention deployment.

1.2. Use of eye-tracker technology to measure attention deployment

The use of eye-tracking measures allows an examination of sustained visual processing and is ideally suited for a study of information processing amongst lonely people because the line of visual gaze can be assessed relatively continuously across long periods of time (Hermans, Vansteenwegen, & Eelen, 1999). In the eye-tracking literature, there are different patterns of attention processing to threat stimuli: (1) initial vigilance and maintenance relates to the orientation of attention to threat (Armstrong & Olatunji, 2012), (2) disengagement difficulties refers to attention being captured by the threat stimuli (see Buckner, Maner, & Schmidt, 2010), and (3) attentional avoidance refers to orienting attention away from threat (see Lange et al., 2011). The latter attention process is thought to occur on a later timescale during extended viewing as it is under voluntary control (Cisler & Koster, 2010). Based on Cacioppo and Hawkley's (2009) model of loneliness, we would expect to find an attentional bias amongst lonely adults that is consistent with the initial vigilance and maintenance pattern of attention.

1.3. Examination of a quadratic relation between loneliness and hyper-vigilance to social threat.

In 2006, Cacioppo and colleagues argued that severe loneliness is qualitatively different from milder forms of loneliness or non-loneliness. Evidence for this discontinuity perspective would be the distinction in behaviour between severe lonely groups and milder lonely or non-lonely groups; severe lonely people should be characterized by a specific type/subset of behaviour. Recently, discontinuity was found in relation to cognitive biases (Qualter et al, 2012): only children in the upper quadrant of loneliness showed a distinct pattern of attention deployment to the socially threatening stimuli, an elevated hostility to ambiguously motivated social exclusion, and higher scores on the rejection sensitivity questionnaire. Guided by the notion that there is something distinct about those scoring very high on loneliness, we examined whether the relation between loneliness and attention deployment to social threat among adults is curvilinear, specifically quadratic, and thus discontinuous.

1.4. The current study

There has been little examination of visual attention and loneliness, specifically in response to social threats that are linked to social rejection or social exclusion. In the current study, we examined whether lonely young adults displayed attentional biases towards socially threatening stimuli, and if so, which pattern of attentional processing was evident. The study consists of testing the pattern of eye-gaze in lonely and non-lonely young adults when viewing social scenes that include both positive and socially threatening stimuli. This is the first study to assess attention-processing styles in lonely adults using eye-tracking technology to gain a continuous measure of selective attention for socially threatening information.

2. Method

2.1. Participants

The sample included 85 undergraduate students (M = 33; F = 52) studying at a university in the North West of England, UK. The mean age of participants was 18 years and 2 months (SD = 4 months)**.** The age range was between 17 and 19 years.

2.2. Measures

2.2.1. Loneliness

Loneliness was measured using the University of California, Los Angeles Loneliness scale (UCLA; Russell, 1996). The scale comprises 20 questions, including ‘How often do you feel that you lack companionship?’ and ‘How often do you feel left out?’. Participants rated how often they felt the way described in each statement on a 4-point scale (1 = never, 2 = rarely, 3 = sometimes, 4 = often). Scores for each statement were summed to give a total loneliness score. The possible range of scores for the full measure was 20-80, with higher scores indicating higher levels of loneliness. In our sample, the loneliness scores ranged from 24-74, with no difference between males and female participants ($t = .404$, $p = .687$). The scale exhibited excellent internal consistency in the current study, $\alpha = .98$.

2.2.2. Video stimuli

Video footage included social scenes of adolescents during lunch or free periods, depicting both positive and negative social interactions. The footage was taken from colleges and schools in the North of England. The video stimuli consisted of eight clips, with each clip lasting 20 seconds; there was a 3 second interval between each clip. The session started with a centrally fixated cross, followed by the viewing of the eight clips. The order of clips was counterbalanced for each participant to reduce order bias. Each clip included some form of socially threatening behaviour (lone individual ignored by a group of peers, discordant body posture [turning of back on another member of the group]) and positive behaviour (smiling, encouragement in the form of nods, leaning into a conversation) that were present on screen at the same time. The clips featured at least two small groups of peers; at least one group showed positive behaviour, whilst the other group included negative behaviour. We used the same video stimuli as that used in an eye-tracker study examining loneliness in children (Qualter et al., 2013).

The threatening clips used in the experiment were classified as ‘unpleasant’ and ‘a good example of rejecting behaviour’ on a 5-point rating scale by two samples of participants (119 undergraduate students [age range: 18-56 years; F = 75; M = 44; 129 children [age range: aged 8-14 years; F = 86; M = 43]).

2.2.3. Eye-tracking system

Eye tracking equipment was used to measure eye movements (visual fixation and scanning) during the course of the eight clips. The eye-tracking device used was an iVIEW X HED model with a dual ocular recording at 200 Hz. The recording was done in stereo bi-ocular recording. Eye movements of each participant were followed precisely and areas of interest were identified and monitored. These areas of interest were (1) threatening stimuli: Individual in the socially rejecting group/dyad or person being rejected/ experiencing negativity from others, and (2) non-threatening stimuli: Individual(s) not in the rejecting group.

Attention was operationalized in terms of eye fixations. An eye fixation was recorded whenever the participant stopped or had a saccade (rapid eye-movement) in one of the two areas of interest. To investigate patterns of attention over time, we used time-blocks to examine the proportion of time fixating on the social threat stimuli relative to the total captured fixation time for each time block. The use of time-blocks is recommended in the literature looking at attention in eye-tracking studies (Hermans et al., 1999). To ensure we captured initial vigilance, then any avoidant patterns of visual attention that may be evident amongst our lonely sample, we examined the first 4 seconds of viewing time independently. The first four seconds were important because the details of the rejection situation are apparent then. We also examined whether the pattern of attention changed over the full 20 seconds of viewing time. These examinations allowed a direct comparison with the findings from the eye-tracking study with lonely children.

2.3. Procedure

After informed consent was gained, participants completed the UCLA loneliness measure in a laboratory room at the University. Participants were then positioned to sit at a pre-determined distance of 60 cm away from the 15-inch laptop display with a 1024 x 768 pixels resolution. The eye tracker was calibrated for each participant and they were asked to view the eight clips as if they were watching television. Eye movements and areas of interest were recorded in the eye-tracker software.

3. Results

3.1. Attention deployment of social threat stimuli

Using regression analyses we examined the linear and quadratic associations between loneliness and attention to social threat stimuli. Loneliness was the predictor variable in these analyses; the percentage of fixation time on the threatening stimuli across 8 time intervals ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, and 4000ms were the criterion variables. Analyses showed significant linear and quadratic relations for loneliness across the first 3 time intervals (0-1500 ms) (linear: $\beta s \geq .47$, $ps < .002$; quadratic: $\beta s \geq 2.20$ $ps < .004$)[1]. Figures 1-3 show these quadratic relations: as expected, those participants very high on loneliness showed a greater frequency to view the socially rejecting stimuli than those in the remainder of the sample. For the remainder of the time intervals, no linear or quadratic relations were found ($\beta s \leq .12$, $ps > .05$). Where we found curvilinear effects, these are reported with the linear effect controlled.

To further examine the quadratic effects and establish whether attention to the social threat stimuli was biased in lonely participants who were in the upper quadrant of loneliness scores, we conducted a 2 (group: lonely versus non-lonely) x 8 (time interval, ending at 500ms, 1000ms, 1500ms, 2000ms, 2500ms, 3000ms, 3500ms, and 4000ms) mixed design MANOVA. Membership of the lonely group was determined by having a score in the upper quadrant of the loneliness scores (N = 10; F = 6)[2]; all other participants were classified as non-lonely (N = 75; F = 46). The MANOVA results showed a main effect of time (F = 44.79, $p < .001$, $\eta p^2 = .80$), and a main effect of lonely group (F = 4.78, p =

[1] We found the same patterns across gender, such that there were significant linear and quadratic relations across the first three time points only (linear: M = $\beta s \geq .52$, $ps < .01$, F = $\beta s \geq .395$, $ps < .003$; quadratic: M = quadratic: $\beta s \geq 2.18$ $ps < .05$, F = $\beta s \geq 2.98$ $ps < .004$).

[2] Scores for people in the upper quadrant represent those with severe levels of loneliness, with means for males (70, SD = 2.16) and females (71.83, SD = 1.60) being within the top quartile of the UCLA scoring range (above 65). Please note that there were no gender differences on loneliness so the effects reported are not driven by gender based differences.

.023, $\eta p^2 = .05$). Further, there was a time x lonely group interaction ($F = 9.81$, $p < .001$, $\eta p^2 = .47$). The time course of attention to the threatening stimuli was different for lonely and non-lonely participants, with means showing lonely participants were fixed on the threatening stimuli within the first 2 seconds of viewing time (see Figure 4). Post-hoc testing using follow-up one-way ANOVAs revealed that lonely and non-lonely participants were different in the amount of viewing time they spent looking at the threatening stimuli over the first three time intervals only (Fs [dfs = 1, 84] $\geq$ 11.85, $ps \leq .001$, $\eta p^2 > .12$). However, after this, the groups no longer differed, with lonely participants spending a similar amount of time as non-lonely participants on the socially threatening stimuli (Fs [dfs = 1, 84] $\leq$ .60, $ps \geq .441$, $\eta p^2 < .007$).

To examine the attention patterns of lonely and non-lonely participants over the full viewing time, we divided each 20-second clip into four 5-second segments. We examined differences between the lonely and non-lonely groups on the percentage of fixation time on the threatening stimuli during the four 5-second segments that made up the full viewing time. ANOVAs revealed differences only during the first 5 seconds consistent with our first set of analyses (F [dfs 1,84] = 3.23, $p < .046$, $\eta p^2 = .05$), but not for the remainder of the viewing time (Fs [dfs 1, 84] < .87, $ps < .201$, $\eta p^2 > .02$). Thus, lonely participants were different in their initial viewing behaviour, but after 2 seconds showed similar avoidance of the socially threatening stimuli as did non-lonely participants. Figure 5 shows the means for lonely and non-lonely adults across the four 5-second segments of viewing time.

3.2. First fixation

Chi-square analyses showed that lonely participants in the upper quartile of the loneliness scores were more likely than chance to have their first fixation on the socially threatening stimuli whilst non-lonely participants were more likely to fixate first on the positive stimuli in the social scene (χ^2 [df 1] = 30.34, $p < .001$).

Figure 1. Linear and quadratic relations between loneliness and the viewing of socially rejecting stimuli at 0-500ms.

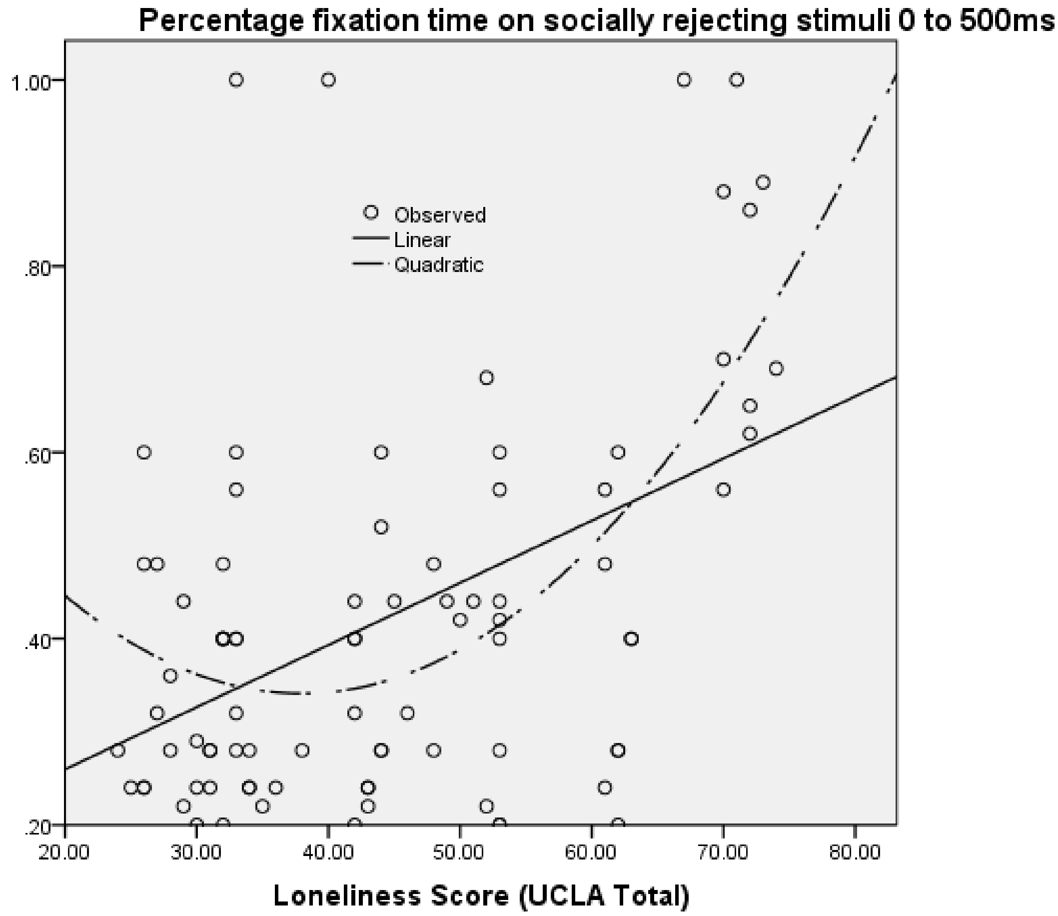


Figure 2. Linear and quadratic relations between loneliness and the viewing of socially rejecting stimuli at 501-1000ms.

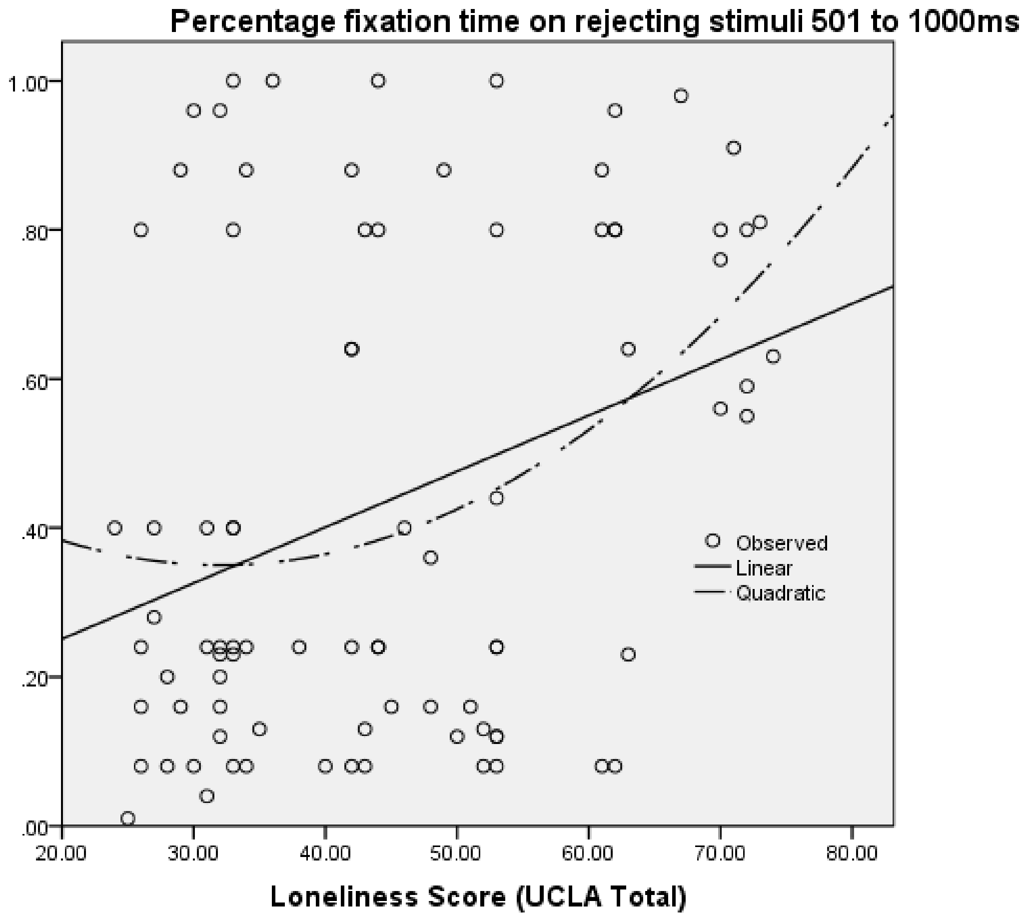


Figure 3. Linear and quadratic relations between loneliness and the viewing of socially rejecting stimuli at 1001-1500ms.

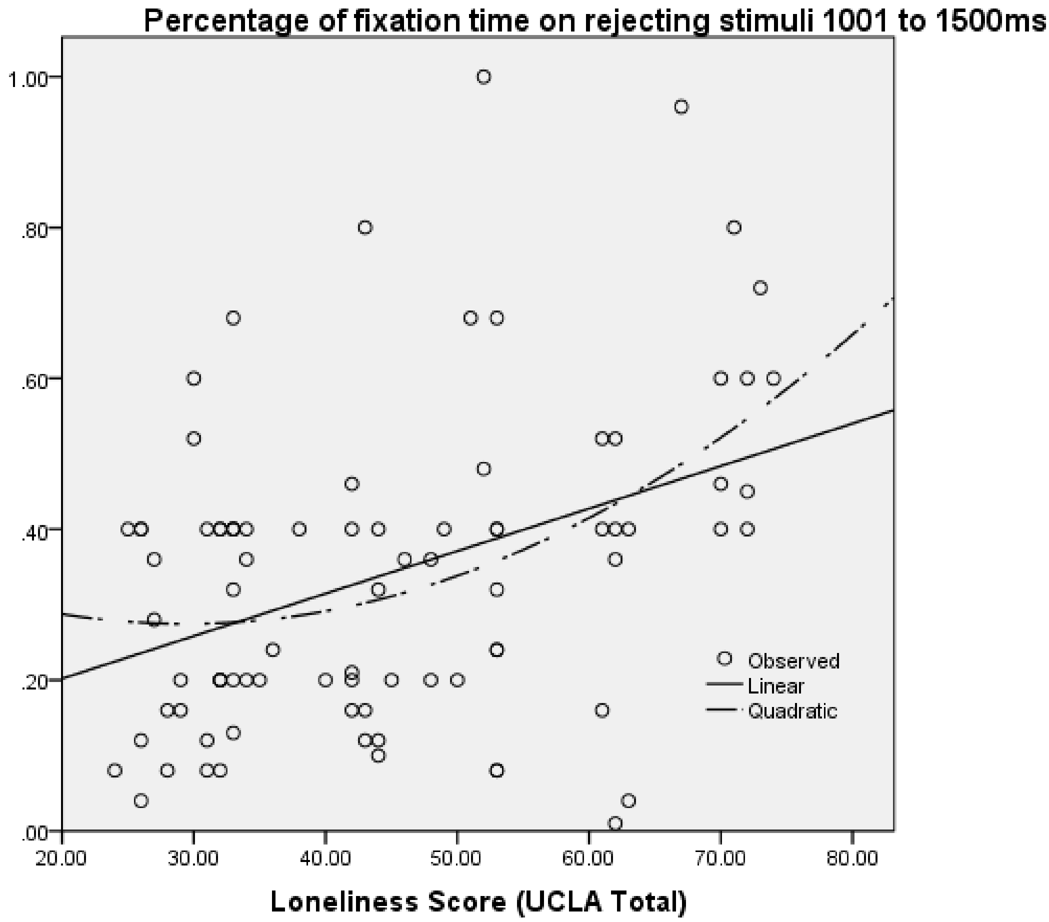
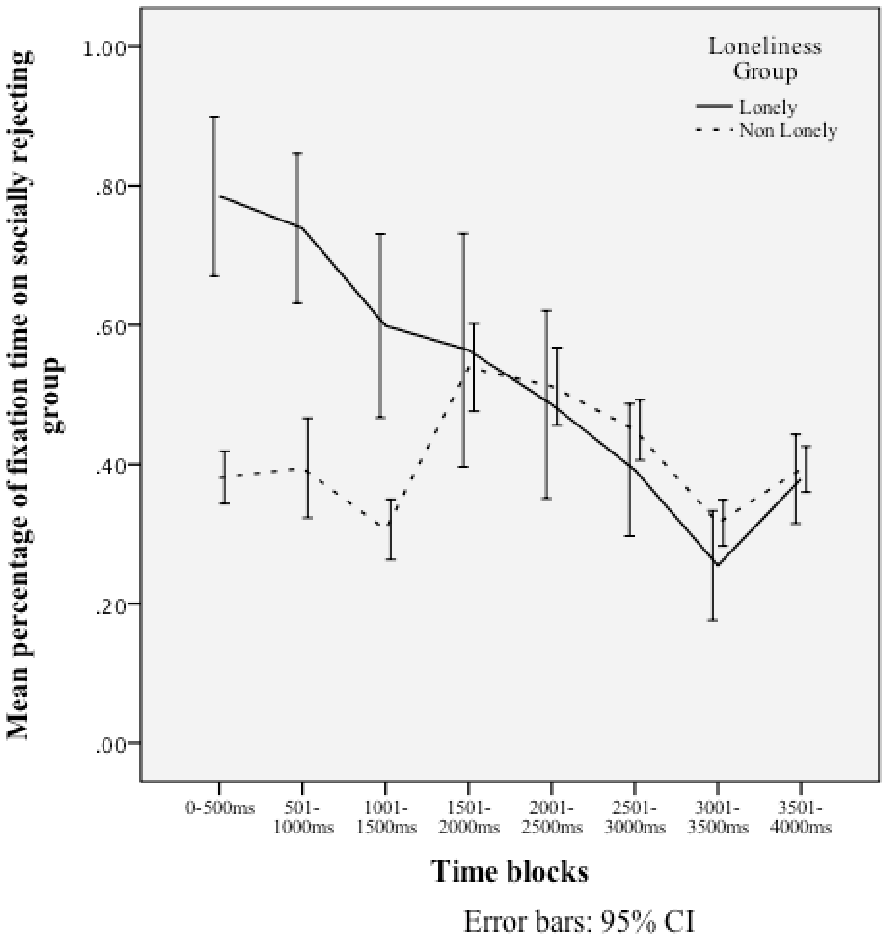
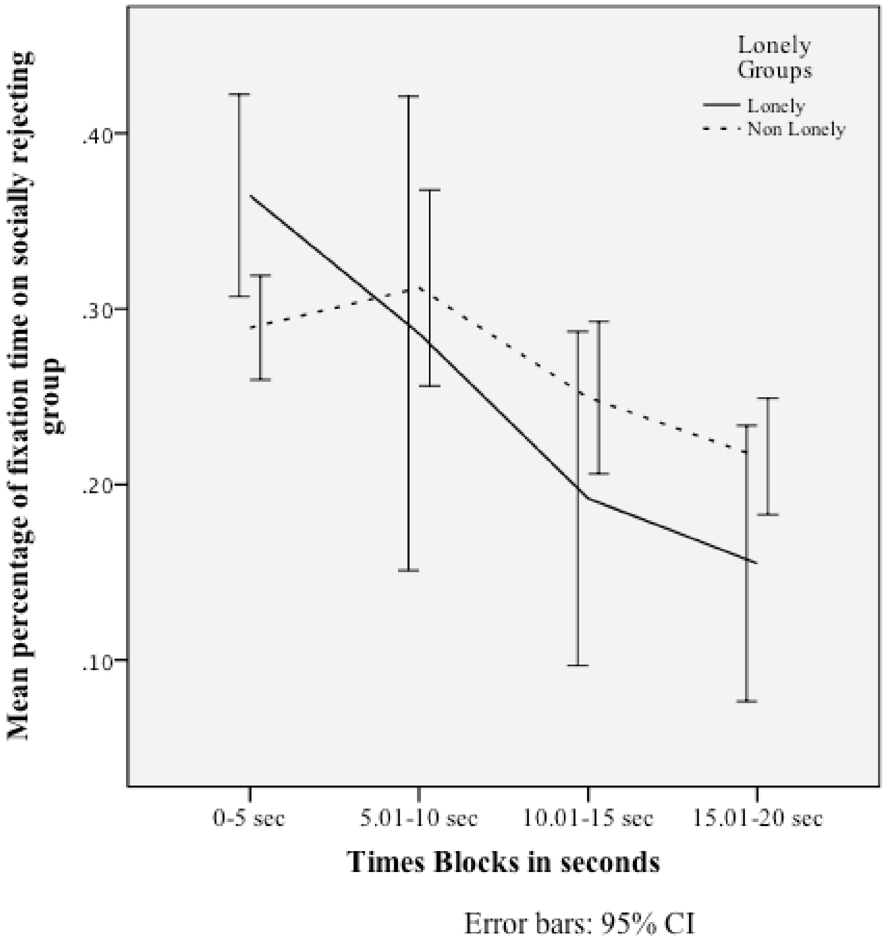


Figure 4. Percent of total fixation time viewing the socially threatening stimuli during the first 4 seconds of viewing time



Notes: Lonely adults were those that scored in the upper quadrant of the UCLA. Post-hoc tests showed that the lonely groups differed for the first 3 time blocks (ending at 1500ms). However, after that, lonely young adults avoided the social threat stimuli in a similar way to non-lonely peers.

Figure 5. Percent of total fixation time viewing the socially threatening stimuli across 5-second segments of the full 20 seconds of viewing time.



Notes: Adults in the lonely groups were those that scored in the upper quadrant of the UCLA. Post-hoc tests showed that lonely young adults were significantly different to non-lonely young adults in their viewing of the social threat stimuli for the first 5 seconds of viewing time only; lonely and non-lonely participants were no different during the other three time blocks (5.01-20 seconds).

4. **Discussion**

The current study is the first study to examine hyper-vigilance to social threat stimuli in lonely adults using eye tracker methodology; it used dynamic social stimuli to determine how hyper-vigilance to social threat might work in real life for lonely people. The findings showed that very lonely young adults, those in the upper quadrant of loneliness scores, were more likely to fixate first on the socially threatening stimuli than were their non-lonely peers. They also appeared to fix their attention on the threat-related stimuli for the first 2 seconds of viewing time, but then showed the same avoidant viewing style as the non-lonely participants. Thus, in line with previous eye-tracker studies on attention processing biases (i.e., Lange et al., 2011), we found initial vigilance towards threat stimuli and evidence of subsequent attentional avoidance of those same stimuli.

These findings are consistent with the model of loneliness that posits lonely people display biased attention for social threat, specifically to rejection and exclusion stimuli (Cacioppo & Hawkley, 2009). Our study also extends previous work by (1) examining visual attention biases in a sample of lonely young adults, and (2) showing that lonely young adults have a pattern of attention processing consistent with initial hyper-vigilance of social threat and later avoidance of these stimuli. Taken together with previous studies assessing social information processing biases of lonely people, there appears to be a robust association between loneliness and cognitive biases for social threat.

4.1. Why do lonely young adults show a different pattern of attention to social threat compared to lonely children?

In the current study, we used the same stimuli to that used in the eye-tracker study looking at loneliness in children, but the pattern of visual attention processing found for lonely young adults was different to that reported for lonely children (Qualter et al., 2013). We found lonely young adults showed an initial vigilance of the social threat stimuli, but this pattern was not previously found for lonely children who had been exposed to the same stimuli. These initial biases in eye-gaze towards social threat may be more pronounced in lonely young adults because they have had longer exposure to their negative expectations. Cacioppo and Hawkley (2009) refer to this as the regulatory loop, where cognitions increase the likelihood that lonely individuals will engage in negative social behaviour (i.e., passivity) that elicit negative responses from others, increasing feelings of loneliness and reinforcing cognitive biases.

Our findings also provide evidence that lonely young adults show attentional avoidance of social threatening stimuli, whilst lonely children showed difficulty disengaging from these stimuli. Changes in cognitive ability, particularly the ability to relocate attention, are likely to be implicated in these changes in information processing and may play a part in maintaining loneliness. For example, the ability to control attention remains immature until cognitive developments in adolescence (Anderson et al, 2001; Puliafico & Kendall, 2006), which could explain why lonely children show a pattern of poor disengagement while lonely young adults show a pattern of visual attention characterized by initial vigilance and then avoidance. Future work should assess executive functioning abilities, such as processing speed and voluntary response suppression, to determine how these abilities impact on the way lonely adults and children attend to threat-related information and disengage from it.

4.2. Implications for interventions

Our findings suggest lonely young adults are hyper-vigilant to social threat. They support the idea that interventions for lonely people should focus on addressing cognitive biases (Masi, Chen, Hawkley & Cacioppo, 2011). The findings also indicate that cognitive-behavioural strategies would best support those that are very high on loneliness and this group should be the primary focus for any interventions.

4.3. Strengths, Limitations, and Directions for Future Study

A major strength of the current study is the use of eye-tracking technology. This enabled the assessment of both early (vigilance) and later (avoidance) processing of attention continuously so that we were able to examine fully whether lonely young adults were hyper-vigilant to social threat. Another strength is the use of video footage from real social situations, which is a more naturalistic measure of social threat than photographic faces that typically serve as a proxy measure for social stimuli (Garner, Mogg, & Bradley, 2006). Future work should examine these attention-processing biases in actual social situations. Such investigations would explore whether there are different patterns of attentional deployment for lonely versus non-lonely people when engaged in actual socially threatening situations. Future work should also investigate whether similar patterns of attention processing are evident when stimuli depicting mild or moderate social threat are used.

There are some limitations to the study that indicate directions for future work. Social anxiety was not measured in the current study. Although London et al. (2007) showed that rejection sensitivity is differentially associated longitudinally with loneliness and social anxiety, there needs to be prospective examination of these constructs using eye-tracker systems. Thus, future work should examine the effects of both loneliness and social anxiety in prospective analyses to determine the significance of loneliness on attention deployment.

The sample we used in the current study was limited to an undergraduate sample with a restricted age range. Future eye-tracker work should look at the attentional biases of older lonely adults to examine whether there are differences in information processing of social threat stimuli between the age groups as such reported using the child sample and current sample.

In the current study, it is likely that the loneliness questionnaire given before the experimental study primed participants to be more susceptible to rejecting/excluding situations shown in the video stimuli and, thereby, affected monitoring behaviour. Future work should counterbalance the completion of the questionnaires and experimental study.

Also, we have not examined how these cognitive biases contribute to behavioural deficiencies and how these relate to persistent feelings of loneliness. Cacioppo and Hawkley (2009) are clear in their proposal that loneliness causes the lonely person to be hyper-vigilance, but London et al. (2007) show that, amongst children, sensitivity to rejection predicts increases in loneliness over time. Without longitudinal research we cannot be certain about which factor affects what over time. The use of different methodologies will also be important: similarity in the findings across prospective studies that measure hyper-vigilance using questionnaires and experimental designs would mean any effects are not an artifact of one particular method and that there is a distinctive pattern of social information processes associated with loneliness over time.

5. Conclusion

Our findings provide some support for Cacioppo and Hawkley's (2009) model of loneliness that proposes loneliness is associated with hyper-vigilance to social threat stimuli. We found evidence that lonely young adults attend to information that is socially threatening more than non-lonely peers. We also found evidence that there is a distinct pattern of attention deployment that characterises lonely young adults who score in the upper quadrant of the loneliness scores. Lonely young adults are (1) more likely to view social threat stimuli as their first fixation than non-lonely peers, (2) more likely to fix their attention on threat stimuli initially, and (3) quickly avoid (after 2 seconds) the social threat in line with non-lonely adults. We interpret these patterns of visual processing as evidence that loneliness is associated with hyper-vigilance to social threat. We propose that these patterns of attention are likely to influence behaviour, including withdrawal and aggression in social situations, and distrust of others, which contribute to the maintenance of loneliness.

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List of Publications from this Thesis

Bangee, M., Harris, R. A., Bridges, N., Rotenberg, K. J., & Qualter, P. (2014). Loneliness and attention to social threat in young adults: Findings from an eye tracker study. *Personality and Individual Differences*, *63*, 16-23

Bangee, M., Cacioppo., S., Balogh., S., Cardenas-Iniguez, C., Qualter, P. & Cacioppo, J.T. Loneliness and Implicit Attention to Social Threat: A high performance electrical neuroimaging study". *Under review*

List of Other Publications

Qualter, P., Brown, S. L., Rotenberg, K. J., Vanhalst, J., Harris, R. A., Goossens, L., **Bangee, M**., & Munn, P. (2013). Trajectories of loneliness during childhood and adolescence: Predictors and health outcomes. *Journal of adolescence*,*36*(6), 1283-1293

Qualter, P., Vanhalst, J., Harris, R., Van Roekel, E., Lodder, G., **Bangee, M**., Maes, M., & Verhagen, M. (2015). Loneliness across the Lifespan. *Perspectives on Psychological Science, 10(2),* 250-264.