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An EEG Study on Loneliness and Recognition Memory

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AN EEG STUDY ON LONELINESS AND RECOGNITION MEMORY

By

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AN EEG STUDY ON LONELINESS AND RECOGNITION MEMORY

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ABSTRACT

Loneliness, the perception of unmet social needs, has been shown to relate to recollection-based recognition deficits, but the relationship between loneliness and recognition memory (i.e., recollection and familiarity) has not been thoroughly examined. The current study hypothesized that more lonely individuals would have lower recognition memory performance, specifically recollection, with smaller ERP parietal old-new effects than less lonely individuals. Forty participants, grouped into less (n = 13) and more (n = 9) lonely groups based on their R-UCLA responses, completed an associative memory task. EEG was used to assess recognition memory effects. Results showed no significant difference in both behavioral and ERP recognition memory effects between lonely groups, showing that lonelier individuals had no specific recollection-based recognition memory deficits. Evidence of a negative trend between loneliness and recognition memory effects was observed. Future research should include more participants and better methodology to explore the loneliness-recognition memory relationship.

Keywords: loneliness, perceived social isolation, memory, recognition memory, electroencephalogram (EEG), event-related potential (ERP)

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The need for social connection and belongingness guides one's motivations, thoughts, behaviors, and emotions (Baumeister & Leary, 1995; Heinrich & Gullone, 2006). Without social connection, people often feel lonely. In a United States national survey, nearly half of 20,000 participating Americans reported that they sometimes or always felt alone or left out, and college students (18-22 years old) reported higher levels of loneliness in comparison to older-aged adults (Cigna, 2018). This staggering statistic suggests that perceived social isolation, or loneliness, is a growing concern with many people, both young and old, feeling lonelier than ever (D'Agostinoa et al., 2019; Heinrich & Gullone, 2006; Qualter et al., 2015).

Considering the prevalence of loneliness, it is important to investigate the impact loneliness has on memory. Researchers have investigated the negative social and emotional impact of loneliness (e.g., negative mood, relationship issues; Ellwardt et al., 2013; Lou et al., 2012) and its associated neural mechanisms (Cacioppo & Cacioppo, 2016; Duzel et al., 2019; Inagaki et al., 2016; Kanai et al., 2012), but relatively little research has been established in understanding loneliness and its impact on memory, specifically associative memory using an electrophysiological technique, among college students. Forming associations between items is crucial for episodic memory. With the increased prevalence of loneliness (Cacioppo & Cacioppo, 2018), settings that foster loneliness may affect college students' memory, which is vital for academic success. If a

relationship between the two can be established, early interventions can then be introduced to college students who are identified as lonely. Therefore, the current study explored the relationship between loneliness and memory, among college students.

Loneliness

Loneliness, or perceived social isolation, is the perception of unmet social needs by quality, quantity, or both in a social relationship (Ellwardt et al., 2013; Hawkley & Cacioppo, 2010). Feelings of loneliness are experienced by everyone at different developmental stages, but researchers have noted that late adolescence and young adulthood are the two developmental stages in which loneliness is pronounced (Qualter et al., 2015). Although loneliness is experienced universally, the discrepancy of one's ideal and current perceived interpersonal relationship is subjective and expressed differently. For example, females are more prone to admit and discuss their feelings of loneliness (Heinrich & Gullone, 2006).

Loneliness can be categorized into two types—transient and chronic (Heinrich & Gullone, 2006; Yi et al., 2018). Transient loneliness is based on situations that cause the momentary feelings of loneliness, whereas chronic loneliness is based on a person's baseline loneliness level characterized by enduring experiences and persistent feelings of loneliness (Heinrich & Gullone, 2006; Yi et al., 2018). Chronic loneliness is a dispositional condition that is constant in a person. According to Yi et al. (2018), chronic loneliness is more detrimental than transient loneliness, and its effects are more persistent regardless of the circumstances. Among the detrimental effects, chronically lonely

individuals have been shown to have poorer memory in comparison to individuals with transient loneliness (Hawkley et al., 2003; van Roekel et al., 2018; Yi et al., 2018).

Before discussing loneliness and its impact on memory, it is imperative to differentiate several related concepts—solitude, negative emotions, and depression. Solitude and loneliness differ in the voluntariness of aloneness. Solitude is a desired social separation whereas loneliness is the perception of either physical or psychological social separation (Ellwardt et al., 2013; Galanaki, 2004; Hawkley & Cacioppo, 2010). Galanaki (2004) reported that solitude or aloneness is believed to be an active, constructive use of time alone. Solitude is a desirable behavior with many benefits (e.g., creativity, concentration), and has lesser negative connotations than loneliness (Galanaki, 2004; Heinrich & Gullone, 2006). In contrast, loneliness is associated with negative emotions and behaviors such as depression, stress, and anxiety that may magnify cognitive dysfunction and emotional instability (Hawkley et al., 2003; Heinrich & Gullone, 2006).

Another loneliness-related concept is negative emotions. Lonely individuals often experience emotions of sadness and negative self-focused thoughts about one's satisfaction and perceived deficits in interpersonal and social relationships (Bastian et al., 2005; Galanaki, 2004). On top of their negative emotions and perceptions, these individuals often demonstrate an ineffective social response and withdraw from social situations (Bastian et al., 2005). Research suggests that lonely individuals either demonstrated a physical or psychological interpersonal separation caused by a real or

perceived loss, temporary absence, rejection, or exclusion in their social context (Galanaki, 2004). Therefore, loneliness differentiated from negative emotions in that it involves not only emotions, but also cognition and interpersonal relationships that may negatively impact memory.

Furthermore, depression and loneliness are to be differentiated. Loneliness has been related to depression (Cacioppo et al., 2014; Cacioppo & Hawkley, 2009; Weeks et al., 1980) and has been suggested to increase the development and maintenance of depression (Cacioppo et al., 2006b; Heinrich & Gullone, 2006). In a meta-analysis of 88 studies, loneliness was shown to have negative effect on depression no matter the age group (Erzen & Cikrikci, 2018). These research studies confirmed that feelings of loneliness can predict the expression of depressive symptoms leading to clinical depression (Heinrich & Gullone, 2006). Loneliness, however, is distinct and separable from depression (Cacioppo & Cacioppo, 2015; Cacioppo et al., 2015; Cacioppo et al., 2006a; Heinrich & Gullone, 2006).

Depression involves appraisals across multiple domains of life with reflections of how one generally feels, whereas loneliness involves only the social domain of an individual's life with reflections of how one feels about one's relationships (Cacioppo & Patrick, 2008; Heinrich & Gullone, 2006). These two concepts differ in the functionality of the result. Depression, a mental disorder, is characterized by apathy, while loneliness urges a person to move forward (Cacioppo & Patrick, 2008). In addition, depressive and loneliness symptoms have shown to be two distinct factors (Cacioppo et al., 2006a). A

factor analysis using the Revised UCLA Loneliness Scale (R-UCLA) to measure loneliness and the Center for Epidemiologic Studies Depression (CES-D) to measure depressive symptoms has provided evidence that the depression items and loneliness items were two distinct factors, which suggests that loneliness and depressed affect are theoretically and statistically different constructs (Cacioppo et al., 2006a). Therefore, it is believed that loneliness on its own will negatively impact memory.

Previous studies have also found that loneliness was positively correlated to stress as well as a possible cause of stress (Cacioppo et al., 2014; Ellwardt et al., 2013). Hawkley et al. (2008) showed that lonely individuals often experience higher levels of social stress. In addition, loneliness has been shown to increase the release and prolong levels of stress hormones (i.e., cortisol) that may even cause feelings of loneliness and/or memory impairment (Cacioppo & Cacioppo, 2015; Cacioppo et al., 2014; Hawkley & Cacioppo, 2010). Thus, the possible interaction between loneliness and memory impairment caused by stress suggests a negative effect on learning and cognition. One cognitive function that is poorly understood concerning loneliness is memory.

Recognition Memory

Recognition memory is a retrieval process that enables one to recognize an event, object, or person as a previously encountered stimulus through recollection and/or familiarity (Rugg & Curran, 2007). According to the dual-process signal detection model (DPSD), a dual-process theory of recognition memory, recollection and familiarity, are distinct retrieval processes (Eichenbaum et al., 2007; Rugg & Curran, 2007; Yonelinas,

2002). Recollection involves remembering specific associated details of prior experiences, whereas familiarity involves knowing or 'feeling' that an event was a prior experience without any associated information (Mayes et al., 2007; Yonelinas, 2002). Recollection reflects one's ability to recall detailed information about studied events and familiarity reflects one's memory strength of studied items (Yonelinas, 2002).

For example, if an individual saw a blue car on the road and recognized and remembered that it was the same blue car in the parking garage seen a few days ago, this would be recollection because they remembered both an item (car) and an associated contextual detail (parking garage). If the individual recognized the blue car, but not the location of where it had been previously seen, this would be familiarity because associated contextual details were not remembered. For recollection to occur, people depend on their associative memory, the ability to form an association between items and their associated contextual details (e.g., car and parking garage; Yonelinas, 2002). This ability to create associations has been measured to dissociate recollection from familiarity (Yonelinas et al., 2010).

Recognition memory, including recollection and familiarity, has been shown to activate different brain regions in the medial temporal, parietal, and prefrontal lobes (Yonelinas et al., 2005). One commonly researched brain region involves the medial temporal lobe (MTL), which is divided into the hippocampus, entorhinal, perirhinal, and parahippocampal cortices (e.g., Eichenbaum et al., 2007; Mayes et al., 2007; Stark et al., 2002; Suzuki, 2007; Yonelinas et al., 2010).

Recollection and familiarity have been dissociated by neural activity in different medial temporal lobe structures. For example, evidence suggests that the hippocampus may be necessary for recollection, whereas regions outside the hippocampus can support familiarity (Yonelinas et al., 2010; Yonelinas et al., 2005). In one study, amnesic patients with hippocampal damage had shown difficulty with association formation, supporting that the hippocampus has a role in recollection (Stark et al., 2002). In addition, functional imaging studies of recollection and familiarity have shown that hippocampal and posterior parahippocampal gyrus activity were consistent with the retrieval of contextual information, suggesting the importance of recollection (Eichenbaum et al., 2007; Mayes et al., 2007). On the other hand, perirhinal cortex activity has been consistent with familiarity (Eichenbaum et al., 2007; Mayes et al., 2007). Further investigation has shown that the medial prefrontal cortex is involved in both recollection and familiarity (Rugg & Curran, 2007; Yonelinas et al., 2010). The current understanding of recognition memory may aid in the neural processes of loneliness and recognition memory.

Loneliness and Memory

Currently, the potential mechanisms underlying the relationship between loneliness and memory are poorly understood. Previous research, however, has shown that loneliness affects cognitive functions (Cacioppo et al., 2014; Cacioppo & Hawkley, 2009; Ellwardt et al., 2013; Heinrich & Gullone, 2006; Spithoven et al., 2017). Studies have reported that lonely older individuals exhibited lower cognitive activity and function, even after controlling for depression (Cacioppo & Hawkley, 2009; Wilson et

al., 2007). Recent research on breast cancer survivors showed that lonelier individuals experienced more problems in concentration and memory with more omissions and longer reaction times in comparison to less lonely cancer survivors despite the different cancer treatment and depression levels (Jaremka et al., 2014).

Further research has shown that lonely older adults tend to develop Alzheimer's disease (AD), a disorder associated with memory loss, more often than non-lonely older adults (Boss et al., 2015; Cacioppo et al., 2014; Cacioppo et al., 2015; Cacioppo & Hawkley, 2009; Ellwardt et al., 2013; Snodgrass & Corwin, 1988; Wilson et al., 2007). Past research has shown that amnesic individuals (i.e., AD and parkinsonian dementia) had difficulty discriminating studied and non-studied images (Snodgrass & Corwin, 1988). Another study showed that lonely elderly individuals were twice as likely to develop AD or symptoms of dementia as those who were not lonely, even when controlling for social isolation (Wilson et al., 2007). These studies support a possible relationship between loneliness and memory (Jaremka et al., 2014; Wilson et al., 2007).

Neuroscience of Loneliness and Memory

Animal research has been used to better understand social isolation, a term analogous to loneliness in people, and memory in humans. Bianchi et al. (2006) demonstrated that socially isolated rats had recognition memory deficits when tested in a novel object recognition task. Further analysis showed that the hippocampus of these isolated rats either developed abnormal synaptic connections or reduced in neuronal connections that may have contributed the memory deficits (Bianchi et al., 2006). Several

other animal studies described by Cacioppo et al. (2014) have shown that social isolation may decrease dendritic arborization in the hippocampus and prefrontal cortex.

In addition, a Magnetic Resonance Imaging (MRI) study on older adults reported that loneliness was associated with smaller volumes of gray matter in the anterior hippocampus, adjacent entorhinal, and parahippocampal cortex, brain regions that may provide temporal and spatial contexts related to memory (Duzel et al., 2019). Other attempts to understand the neural aspect of loneliness showed that individuals with a small online social network generally displayed a smaller middle temporal gyrus and entorhinal cortex, which are brain regions related to associative memory (Cacioppo & Cacioppo, 2016; Kanai et al., 2012). The analysis also showed that higher levels of loneliness were associated with smaller volumes of gray matter in the left posterior parahippocampal gyrus, suggesting a role in memory (Cacioppo & Cacioppo, 2016; Duzel et al., 2019; Kanai et al., 2012). This research provides evidence that loneliness may have neuronal impacts on brain regions activated during recognition memory (e.g., Bianchi et al., 2006; Cacioppo et al., 2014; Duzel et al., 2019).

With loneliness related to stress, there is a need for neural understanding of how stress and loneliness may impact memory. Further physiological explanations have found that social isolation reduces the biosynthesis of allopregnanolone (ALLO), which is a progesterone-derived, endogenous neuroactive steroid in the rodent's brain. ALLO has been shown to regulate hypothalamic-pituitary-adrenocortical (HPA) activity and enhance gamma-aminobutyric acid (GABA) inhibitory signals (Cacioppo et al., 2014;

Cacioppo et al., 2015; Cacioppo & Cacioppo, 2015; Xia & Li, 2018). It has also been shown that repeated stress contributes to the downregulation of ALLO synthesis (Xia & Li, 2018). This lack of ALLO synthesis in lonely animals' brain supports that chronic stress reduces ALLO synthesis, thus, leading to a vicious circle of continued reduced ALLO synthesis and elevated HPA activity (Cacioppo & Cacioppo, 2015; Xia & Li, 2018). Elevated cortisol levels may impact hippocampal-dependent memory (Herman et al., 2016; McCullough et al., 2015).

At the same time, ALLO is known to enhance GABA inhibitory signals by prolonging the opening time of chloride channels within the $GABA_A$ receptors; thereby, increasing the effects of GABA and decreasing emotional disturbance and stress responses (Cacioppo & Cacioppo, 2015). These $GABA_A$ receptors are found in the glutamatergic neurons of some brain regions important for memory, such as the hippocampus (Cacioppo & Cacioppo, 2015). As a result, reduced levels of ALLO in the hippocampus may impair hippocampal neurogenesis and increase sympathetic arousal (e.g., stress response) caused by the HPA axis and reduced GABA activity (Cacioppo & Cacioppo, 2015). Xia and Li (2018) investigated the effects of reduced ALLO levels that are known to downregulate in neurons of the hippocampus and medial prefrontal cortex. These brain areas are believed to be essential for encoding and retrieval of episodic memories (Eichenbaum et al., 2007; Mayes et al., 2007; Stark et al., 2002; Suzuki, 2007; Yonelinas et al., 2010). The relationship between loneliness, stress, and the downregulation of neurons in the MTL supports loneliness' negative impact on

associative memory.

The neurological understanding of both loneliness and associative memory formation on the MTL has provided evidence that loneliness may negatively impair associative memory performance (e.g., Bainchi et al, 2006; Cacioppo & Cacioppo, 2016; Duzel et al., 2019; Eichenbaum et al., 2007; Kanai et al., 2012; Mayes et al., 2007). Based on the neurological findings, it is believed that electrophysiological measures could be used to confirm these predictions that loneliness will negatively impact associative memory. However, little to no known research using electroencephalography has looked at the relationship between associative memory and loneliness.

Electroencephalography

Electroencephalography (EEG) is a non-invasive electrophysiological technique that measures changes in electrical potentials produced by the neural excitations of the underlying cortical brain structures (e.g., Luck, 2014; Teplan, 2002; Woodman, 2010). EEG signals are read by metal electrodes, normally placed according to the International 10/20 System (see Figure 1), and conductive fluid from the scalp surface (Teplan, 2002). The International 10/20 system, formalized by Jasper (1958), standardized the physical placement and designation of the electrodes on the scalp based on the proportional distances of the head to two prominent anatomical landmarks (i.e., nasion and inion) in percentages of 10 and 20 (Teplan, 2002). The electrode placements are labeled by letters according to their adjacent brain areas (e.g., F for frontal, P for parietal). Numbers are assigned to indicate the hemisphere—odd numbers indicating electrodes on the left

hemisphere and even numbers indicating electrodes on the right hemisphere. A "z" representing the number zero, indicate electrodes on the midline.

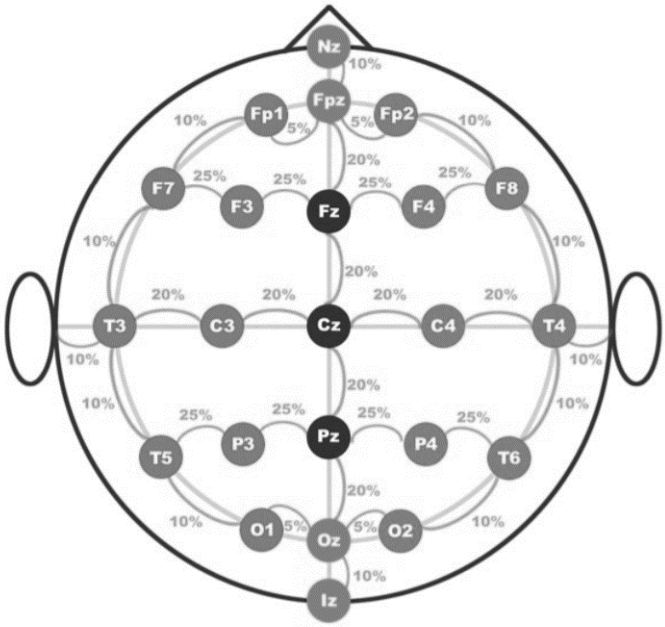

Figure 1. The International 10/20 System of EEG Electrode Placement. (Fp = frontal pole. F = frontal. C = central. P = parietal. O = occipital. T = temporal. Nz = Nasion. Iz = Inion). Adapted from "10/20 System Positioning: Manual," by Trans Cranial Technologies.

EEG and Associative Memory

Many EEG studies on memory often use a simple averaging technique from event-related potentials (ERPs) that measure scalp-recorded changes of neural responses, primarily generated by postsynaptic potentials, to a specific event (Luck, 2014; Rugg & Allan, 2000; Woodman, 2010). ERPs are often used to study memory as it provides precise measurement of temporal characteristics of neural activity in milliseconds and

allows easy comparison of brain activity associated with different responses to the same item (e.g., hits vs. misses and hits vs. false alarms; Friedman & Johnson, 2000; Rugg & Allan, 2000; Wilding & Ranganath, 2012). ERPs are also unique in recognition memory as it can measure information processing such as encoding and retrieval without assessing behavioral response (Friedman & Johnson, 2000). Furthermore, ERP evidence supports the DPSD model of memory used in this study to differentiate recollection and familiarity (Yonelinas, 2002).

Numerous studies have demonstrated that ERPs are used to study familiarity and recollection in recognition memory with specific old-new effects, which refers to the differential ERP responses to recognized versus new items (Ecker et al., 2007; Friedman & Johnson, 2000; Rugg & Curran, 2007). Old-new effects are differences between correctly identified studied and new items (i.e., hits vs. correct rejections) with the "Old" in the old-new effect is more positive- going amplitude than "New". Late positive components (LPC) such as the P300 component has shown to be sensitive to memory with associated details (Curran, 2004; Jaeger & Parente, 2008; Rugg & Curran, 2007). Studies have found that a parietal, positive-going ERP effect (parietal old-new effect) with onset between 400-800 ms attributed to recollection-driven recognition (Curran, 2004; Jaeger & Parente, 2008; Rugg & Curran, 2007). Moreover, studies have shown that a mid-frontal old-new effect (FN400 old-new effect) occurring between 300-500 ms attributed mostly to familiarity-driven recognition (Curran, 2004; Jaeger & Parente, 2008; Rugg & Curran, 2007).

Curran (2004) showed that the parietal old-new effect, especially on the left parietal regions, was observed when individuals remembered a previously presented word, associated mostly with recollection. He also found that the mid-frontal old-new effect (FN400 old-new effect) occurring between 300 – 500 ms was observed when individuals noted that they knew a word, associated mostly with familiarity (Curran, 2004). Similar ERP parietal and mid-frontal old-new effects have been found in memory studies with picture stimuli (e.g., Ecker et al., 2007; Mollison & Curran, 2012). Parietal old-new effects were found near the left and right parietal electrode sites (P3 and P4) with a larger old-new effect on the left region and FN400 old-new effect were found near the left and right frontal electrode sites (F3 and F4; Curran & Friedman, 2004). Therefore, recollection and familiarity can be discriminated by comparing parietal and mid-frontal old-new effects, respectively, with picture stimuli (e.g., Ecker et al., 2007; Rugg & Allan, 2000; Wilding & Ranganath, 2012).

Current Study

Previous research has examined the negative impacts of loneliness and the effects it may have on memory; however, most of the research has used elderly samples (Cacioppo et al., 2014; Hawkley et al., 2003; Heinrich & Gullone, 2006; Yi et al., 2018). Few studies have examined the effects of loneliness on memory using an electrophysiological measure, such as EEG, in young adults. In addition, evidence has shown that loneliness is distinct from negative emotions and other related behaviors (Cacioppo et al., 2006a; Galanaki, 2004). The current study investigated the relationship

between loneliness and recognition memory. It was hypothesized that lonelier individuals will have lower recollection memory performance than less lonely individuals. Furthermore, more lonely individuals will show smaller ERP parietal old-new effects, reflective of recollection, in comparison to less lonely individuals. It was predicted that there will be no difference in ERP mid-frontal old-new effects, reflective of familiarity, between the two loneliness groups.

METHOD

Participants

Forty undergraduate students were recruited from the psychology department at Stephen F. Austin State University through an online database, SONA Systems. All participants were at least 18 years old and reported no signs of red-green color blindness. Two participants were dismissed due to hairstyles that impeded electrode placement on the scalp, one participant was dismissed due to software technical issues, and one participant was excluded due to no response for old images with the associated background. The total sample of 36 undergraduate students (24 females, 12 males) was used in the analysis. All participants received course credit upon completing the study. Participants were predominantly White (n = 28; 77.8%), between the ages 18 to 23 (M = 19.32, SD = 1.27). Of the total sample, 22 participants were divided into the less lonely (n = 13) and more lonely (n = 9) groups based on R-UCLA scores. These participants were used in further analysis with the behavioral task and EEG data. The remaining 14 participant's data were not used in the planned analysis but were included in an exploratory analysis.

Materials

Revised UCLA Loneliness Scale

The Revised UCLA Loneliness Scale (R-UCLA; Russell et al., 1980) was used to measure participants' feelings of loneliness and social isolation. This 20-item self-report

questionnaire consists of 10 statements each dealing with satisfaction or dissatisfaction in one's social relationships. Sample items included, "I lack companionship" and "I feel in tune with the people around me." Items were rated on a 4-point Likert scale with anchors, where 1 (*Never)* and 4 (*Often)*. Positively phrased statements (see Appendix A) were reverse coded, with anchors of 1 (*Often)* and 4 (*Never)*. Scores were summed to obtain a total score of loneliness ranging from 20-80 with higher scores signifying higher feelings of loneliness. A Cronbach's alpha of .92 was observed, indicating a good internal consistency.

The Center for Epidemiologic Studies Depression Scale-Revised

Participants completed the Center for Epidemiologic Studies Depression Scale-Revised (CESD-R; Eaton et al., 2004) that measured their symptoms of depression state based on the Diagnostic and Statistical Manual, fifth edition (DSM-5). The 20-item Likert scale is a self-report measure that can be separated into eight different subscales with anchors of 0 (*Not at all or less than one day*) and 4 (*Nearly every day for 2 weeks*). Sample items included, "My appetite was poor" and "I could not shake off the blues." A total CESD-R score is obtained by summing all the responses to the 20 items with scores ranging from 0 to 80. A total score of 16 or above indicates a person's risk of clinical depression. The depression scale was used as a covariate because depression has been noted to be correlated with and a possible result of loneliness. A Cronbach's alpha of .65 was observed.

The State-Trait Anxiety Inventory T-Anxiety Scale

The State-Trait Anxiety Inventory T-Anxiety Scale (STAI T-Anxiety; Spielberger, 1983) was used to control for any loneliness-anxiety interaction. The STAI T-Anxiety is a 20-item scale that assessed the participants' predisposition to react with anxiety in stressful situations (Spielberger, 1983). Individuals were asked to rate these 20 items on a 4-point Likert scale with anchors of 1 (*Almost Never*) to 4 (*Almost Always*). Examples of trait anxiety items included, "I feel pleasant" and "I lack self-confidence." The total trait anxiety score was obtained by reversing the scores of the ten positively phrased items (see Appendix C) before summing all the items. The possible trait anxiety scores ranged from 20 to 80 with higher scores indicating higher trait anxiety levels. A Cronbach's alpha of .94 was observed, which showed good internal consistency.

Perceived Stress Scale

Similar to the depression and anxiety scales, the Perceived Stress Scale (PSS; Cohen et al., 1994) was used as a covariate to measure the perception of stress. This 10-item scale rated on a 5-point Likert scale with anchors of 0 (*Never*) and 4 (*Very Often*). An item from the scale includes, "How often have you felt that you were unable to control the important things in your life?" The PSS had four reverse-coded items. An example of the reverse-coded item includes, "How often have you felt confident about your ability to handle your personal problems?" Scores were obtained by summing all the items. The possible scores ranged from 0 to 40 with higher scores indicating higher perceived stress. Low stress, moderate stress, and high perceived stress have scores

ranging from 0-13, 14-26, and 27-40, respectively. Good internal consistency (α = .88) was found.

Attention Check

An attention check item was included in each of the scales that instructed participants to select response option 4 from a Likert scale. Participants who failed two of the three attention checks were excluded from the analyses. None of the participants failed the attention checks.

Memory Task Stimuli

Participants completed a memory task that assessed the individual's associative memory. Participants were asked to identify previously presented images with the respective images' colored background (see Figure 2). These images were neutral-valence, everyday objects obtained from a commonly used image database (Stark et al., 2013). All the images were 486 x 486 pixels, and the study images had 48-pixel-wide background color of red, blue, and green (Mayes et al., 2007; Noh et al., 2018; Yonelinas et al., 2010). The stimuli were presented to the participants using E-prime 2.0, a software program by Psychology Software Tools, in two phases—study phase and test phase—that took approximately 30 minutes to complete (Stark et al., 2015).

Figure 2A

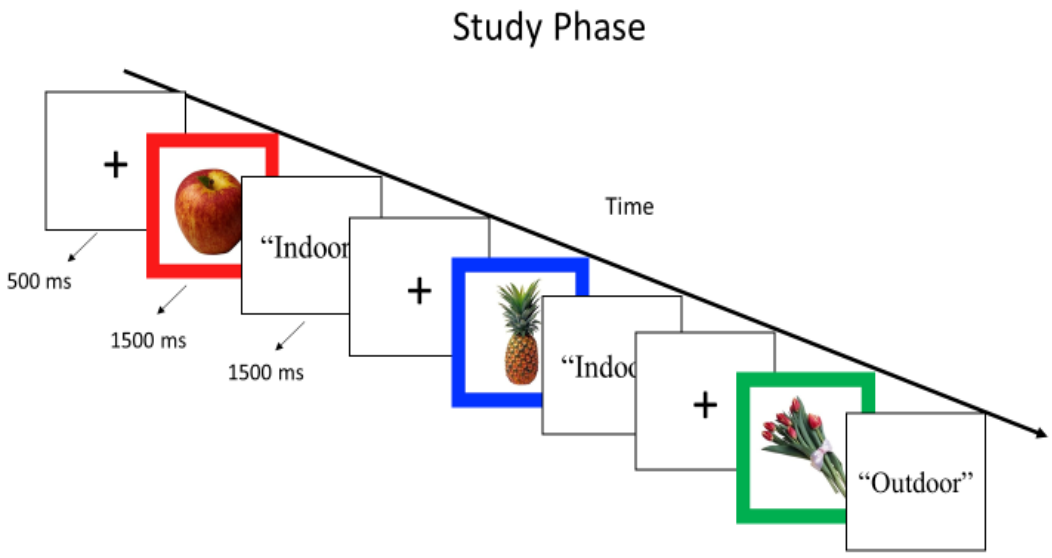

Figure 2B

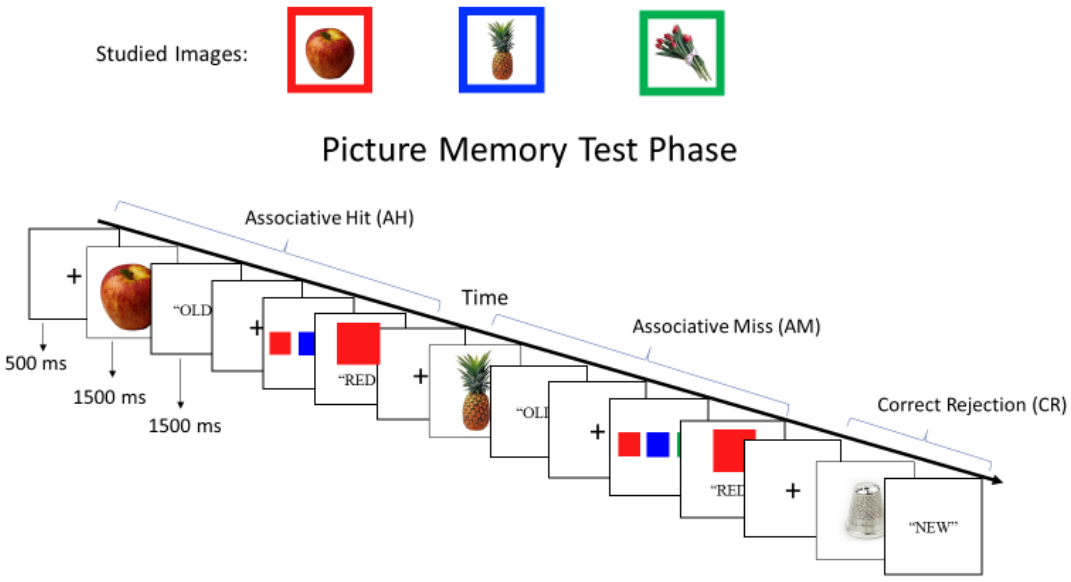

Figure 2. Study Phase (Panel A) and Memory Task (Panel B) Phase of Associative Memory Task.

Before the actual memory task, participants went through a familiarization phase. In this phase, the participants completed a short practice block of a single 6-image study task followed by a single 12-image test to ensure understanding of the memory task. The actual memory task consisted of 150 study images and 300 test images that were presented in two sessions. Each session consisted of 75 randomized study images followed by 150 randomized test images—75 studied (old) and 75 not studied (new) images. Three versions of the memory task were created to counterbalance the color backgrounds of 50 red, 50 blue, and 50 green with the 150 study images. Both study and test images were randomized for each participant, and breaks were included after every 75 images so that the participants could periodically rest their eyes. See Figure 3.

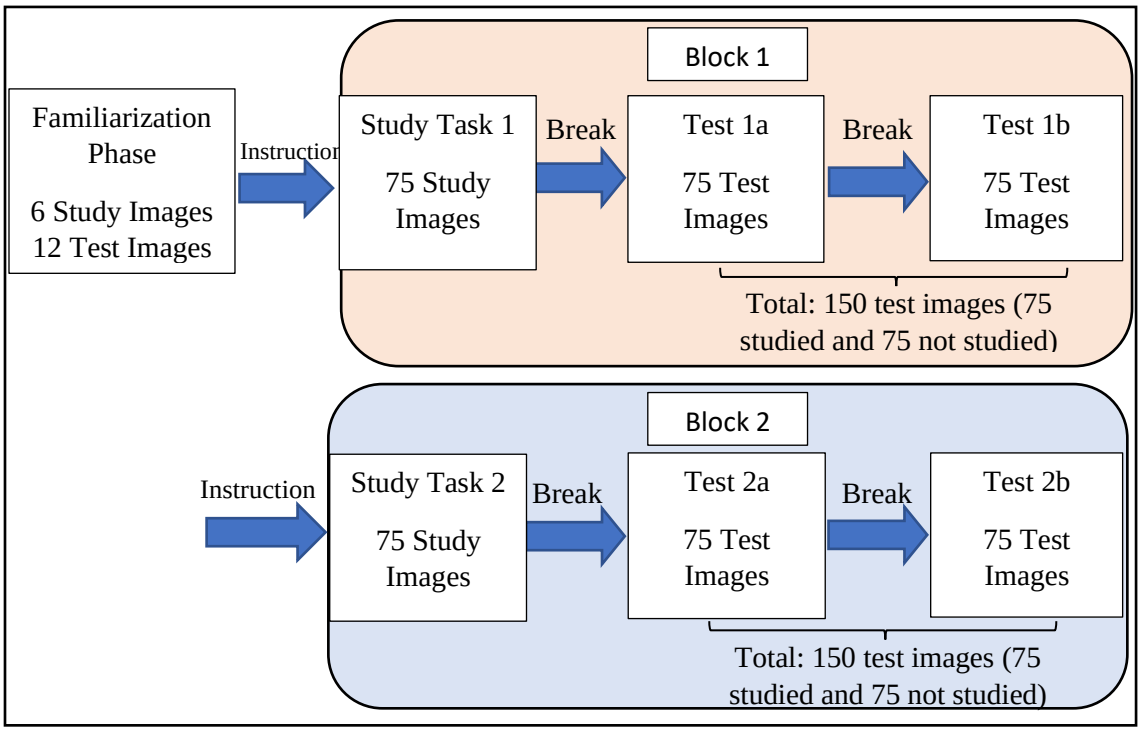

Figure 3. The order of the memory task.

In the study task, participants subjectively decided if the presented objects were an indoor (item found inside of the home) or outdoor (item found outside of the home) item via two keys on the keyboard. The study trials included a 500 ms fixation sign (+), a 1500 ms presentation of an image, and a 1500 ms response screen (see Figure 2A). The study task ensured that participants were paying attention to the studied items and was not analyzed. Following this study task, participants completed a recognition memory test, where they were presented the previously studied images (without their colored backgrounds) and new images. Participants responded to whether an image was old (i.e., previously studied) or new (i.e., never seen before) on each trial by selecting 1 or 2, respectively, on the keyboard. If participants selected an image as old, they were asked to report whether the background of the old image was red (1), blue (2), or green (3), or to leave it blank if they were unsure of the color. The test trials included a 500 ms fixation sign (+), a 1500 ms presentation of an image, and a 1500 ms response screen. An additional 1500 ms presentation of the colored backgrounds and a 1500 ms response screen requesting for the colored background was included if participants identified an image as old. See Figure 2B.

Apparatus Recording

Electroencephalogram (EEG)

Electroencephalography (EEG) was used in the study to obtain neural responses and to assess event-related brain potential (ERP) old-new effects while participants completed the memory task (Friedman & Johnson, 2000; Ecker et al., 2007). The

BrainMaster Discovery 24E hardware, a lightweight and portable device, which consists of 21 channels connected to a standard electrode cap with two reference electrodes, was used. The device has a sampling rate of 256 Hz. EEG data in this study was recorded from 21 electrodes placed on the elastic cap on the skull based on the International 10/20 system with reference electrodes on the ear lobes. The impedance of each electrode was checked using the 1089 MK III NP Checktrode (UFI Instruments, 2007). Eleven participants (less lonely, $n = 5$; moderate lonely, $n = 2$; more lonely, $n = 4$) had impedances below 30 KΩ and 25 participants (less lonely, $n = 8$; moderate lonely, $n = 12$; more lonely, $n = 5$) had impedances above 30 KΩ. A 60-Hz Notch filter was used for EEG data collection.

Procedure

This in-person study was conducted in an SFA psychology laboratory. After reading and signing a consent form, all participants were requested to remove their jewelry (e.g., earrings, necklace) and hair ties before being seated in front of a computer monitor to complete the memory task (see Figures 2 and 3). The dimensions of the participant's head were measured before placing an appropriate-sized electrode cap on the participant. Each electrode was filled with Electro-gel. The electrodes were attached to the EEG amplifier and the brain waves were displayed on another computer monitor. Once the EEG was set up, the impedance of each electrode was checked. A brief explanation of the observed brain waves on the screen was given to the participants, and participants were advised to minimize movements (e.g., eye, muscle) when images were

presented. The computer screen's brightness and contrast were adjusted to the lowest possible setting as the room lights were switched off during the memory task.

Then, the participants completed the study and memory test phases of the memory task. After completing the memory task, participants completed a Qualtrics survey consisting of the R-UCLA (Appendix A), CESD-R (Appendix B), STAI T-Anxiety scale (Appendix C), and PSS scale (Appendix D). Each scale was presented in blocks, which was randomized for each participant. The participants also completed a demographic questionnaire with questions on biological sex, gender, age, ethnicity, race, classification, and handedness (Appendix E) before being debriefed. Participants were thanked for their participation and were given course credit.

Data Processing and Analysis

Behavioral Task Data Processing and Analysis

Associative hits (AHs), associative misses (AMs), and correct rejections (CRs) were measured based on the participant's memory task responses. Associative hits represented the correct identification of old images (i.e., previously presented images) with the correct color background. Associative misses represented the correct identification of old images without the correct color background. Correct rejections represented the correct identification of new images. The proportion of correctly identified colored backgrounds for old images represented associative memory performance.

For the behavioral task, the quasi-independent variable was the loneliness groups.

The two measured variables were the *d*-prime (*d'*) scores and the proportion of correctly identified colored backgrounds to old items. *d'* scores were calculated by obtaining the *z*-scores of the AHs and AMs (i.e., the proportion of old stimuli responded as old to actual old stimuli; H = (AH + AM)/150) and false alarms (FA; i.e., new stimuli responded as old to actual new stimuli; $d = z(H) - z(FA)$). The proportion of correctly identified colored backgrounds to old items was calculated by obtaining the proportions of associative hits to the total old response. See Figure 4. Two independent *t*-tests were performed to test if lonelier individuals had poorer memory performance and whether memory performance was specific to recollection.

Figure 4

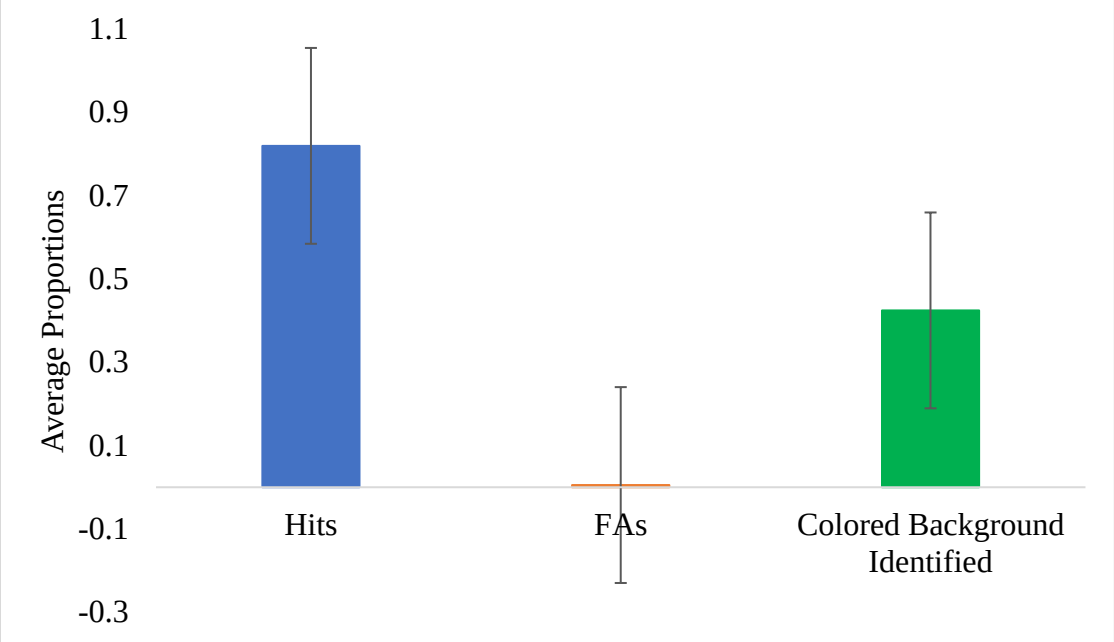

Figure 4. Bar graph of the average proportion of hits, FAs, and colored background correctly identified from *d'* and proportions of AH scores for 36 participants.

Electroencephalography Data Processing and Analysis

EEG data on locations on the left and right mid-frontal (F3 and F4) and parietal (P3 and P4) lobes were processed off-line using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolboxes in MATLAB version R2017a (Mathworks, Natick, MA). EEG data were first filtered with a 0.1Hz high-pass filter, and then a 30.0 Hz low-pass filter using an infinite impulse response Butterworth filter (Luck, 2014). An artifact correction followed by an artifact detection technique was used to ensure clean data. Independent component analysis (ICA), an artifact correction method, was then used to detect and remove consistent electrical noise such as eyeblinks, eye movements, and muscle and heart activity. ERPs were isolated in epochs of 200 ms baseline prior to and 1000 ms following the stimulus onset (Wilding & Ranganath, 2012). Then, artifacts such as blinks, saccadic eye movements, and muscle movement that were not corrected were detected using ERPLAB's artifact detection algorithms of a 200 ms moving window with a peak-to-peak voltage threshold of 75μV and a window step of 100 ms (Luck, 2014). Epochs with detected artifacts were excluded from the ERP average means of each participant.

The averages of the epochs of studied and unstudied items were obtained through the behavioral responses of each participant from E-prime. Individual ERP plots were obtained before computing the ERP grand mean averages of AH, AM, and CR for the mid-frontal left (F3) and right (F4) and the parietal left (P3) and right (P4) electrode sites in both the less lonely and more lonely groups, respectively. The latency interval of 400 –

800 ms for ERP parietal old-new effect discussed in previous literature was not consistent with the observed ERP data. Visual inspection on ERP plots for all 36 participants indicated that the ERP old-new effect at P3 and P4 was observable between 400 – 600 ms, peaking at approximately 500 ms. Another component was observed peaking at an approximate 800 ms, which overlapped with the originally planned LPC window of 400 – 800 ms. This component was believed to be the late posterior negative component (LPN) that occurs after 600 ms (Mecklinger et al., 2016). Considering these observations, the window was set to 400 – 600 ms for the parietal old-new effect and 300 – 500 ms for the mid-frontal old-new effect, which are reflective of both recollection and familiarity, respectively.

The experimental design of the study was a 3 (ERP Conditions: Associative Hit, Associative Miss, Correct Rejection) × 2 (Loneliness Level: Less Lonely, More Lonely) factorial mixed design measuring ERP mean amplitudes at P3, P4, F3, and F4. Four one-way, within-subjects analysis of variances (ANOVAs) involving the 36 participants were conducted to first determine if there were ERP memory effects at these electrode sites. Four mixed ANOVAs were conducted to examine the impact loneliness has on ERP memory effects on these electrode sites. In addition, four analyses of covariances (ANCOVAs) were conducted to ensure that loneliness alone, and not depression, anxiety, or stress, influenced the ERP mid-frontal and parietal old-new effects. Post-hoc analyses using Bonferroni correction for the significant results in the ANOVAs and ANCOVAs were also conducted.

RESULTS

Data Cleaning and Assumptions

Data were cleaned, tested for assumptions, and analyzed with IBM SPSS Statistics (Version 26). A total of 37 participants completed all sessions of the study. All participants passed the attention check items in the scales. One participant had missing data for AH and AM and was excluded from the analyses. Univariate outliers and tests for normality were assessed. Univariate outliers for the variables were detected by identifying scores that were 3.25 standard deviations above and below the mean. No outliers were found. Depression data showed a slight positive skew, and the data were square root transformed to obtain a normal distribution. All assumptions for the independent *t*-tests and ANOVAs were met, and no outliers were found. The assumption of independence of covariates with groups was violated in the ANCOVAs, which was likely due to the nonrandom assignment of groups (Miller & Chapman, 2001); therefore, ANCOVA results should be interpreted cautiously. A 95% confidence interval (CI) and Bonferroni correction were used in the analyses.

The R-UCLA scores for each participant were calculated to determine whether the participants met the criteria for the less lonely and more lonely groups. Participants scoring one half standard deviation (0.5*SD* = 5.91) below and above the mean (*M* = 41.08) on the R-UCLA were grouped into the less lonely (*n* = 13; *M* = 30.23, *SD* = 4.85) and more lonely (*n* = 9; *M* = 57.89, *SD* = 6.99) groups, respectively. Participants with

moderate lonely scores were not included in further analyses (n = 14; M = 40.36, SD = 3.25).

Covariate Results

Three independent t-tests were conducted to determine if the covariates were significantly different among the loneliness groups. The first independent t-test revealed that less lonely individuals (M = 4.62, SD = 0.54) had lower transformed depression scores than more lonely individuals (M = 5.79, SD = 0.77). This difference, -1.16, was significant, $t(20) = -4.18$, $p < .001$, $d = -1.82$. The second independent t-test revealed that less lonely individuals (M = 36.08, SD = 8.67) had lower anxiety scores than more lonely individuals (M = 56.56, SD = 11.75). This difference, -20.48, was significant, $t(20) = -4.71$, $p < .001$, $d = -2.04$. The third independent t-test revealed that less lonely individuals (M = 14.38, SD = 5.52) had lower stress scores than more lonely individuals (M = 25.89, SD = 4.83). A difference of -11.50 showed significance, $t(20) = -5.05$, $p < .001$, $d = -2.19$. These results reflected that less lonely and more lonely individuals had significantly different depression, anxiety, and stress scores. See Table 1.

Behavioral Task Results

An independent t-test revealed that less lonely individuals (M = 3.06, SD = 0.70) had slightly higher *d'* scores than more lonely individuals (M = 2.85, SD = 0.69), but this behavioral difference, 0.21, was not significant, $t(20) = 0.71$, $p = .49$, $d = 0.30$. Another independent t-test revealed that less lonely individuals (M = 0.42, SD = 0.061) were able to correctly identify the color backgrounds slightly more than the more lonely individuals

(*M* = 0.38, *SD* = 0.074), but the difference between the lonely groups, 0.034, was not significant, *t*(20) = 1.19, *p* = .25, *d* = 0.60. See Table 1.

Table 1.

Results of Behavioral Recognition Memory Analyses and Covariates Between Loneliness Groups

Variable	Less Lonely		More Lonely		*t(20)*	95% CI	*Cohen's d*
	M	*SD*	*M*	*SD*			
d' scores	3.06	0.70	2.85	0.69	0.71	-0.42, 0.85	0.30
Proportion of AH	0.42	0.061	0.38	0.074	1.19	-0.026, 0.095	0.60
Depression	4.62	0.54	5.79	0.77	-4.18***	-1.75, -0.58	-1.82
Anxiety	36.08	8.67	56.56	11.75	-4.71***	-29.54, -11.42	-2.04
Stress	14.38	5.52	25.89	4.83	-5.05***	-16.26, -6.75	-2.19

*** $p < .001$

Electroencephalography Results

ERP Parietal and Mid-frontal Old-New Effects

Four one-way, within-subjects ANOVAs (ERPs: AH, AM, CR) were conducted to test ERP parietal and mid-frontal old-new effects for the 36 participants. It was expected that both AH and AM will have higher scores than CR at all electrode sites, with AH being greater than AM and CR at the parietal electrode sites. Results for the three ERP conditions at P3 was statistically different, $F(2, 70) = 4.21$, $p = .019$, $\eta_p^2 = 0.11$. Post-hoc analysis showed that the ERP difference between AM and CR (AM–CR) was significant, $M = 0.75$, $SE = 0.23$, $p = .008$. ERP differences between AH and CR (AH–CR; $M = 0.44$, $SE = 0.27$, $p = .32$) and AH and AM (AH–AM; $M = -0.31$, $SE = 0.28$, $p = .83$) were not significant. The results for ERP conditions at P4 were not significantly different, $F(2, 70) = 2.22$, $p = .12$, $\eta_p^2 = 0.060$. See Figure 5.

Figure 5A

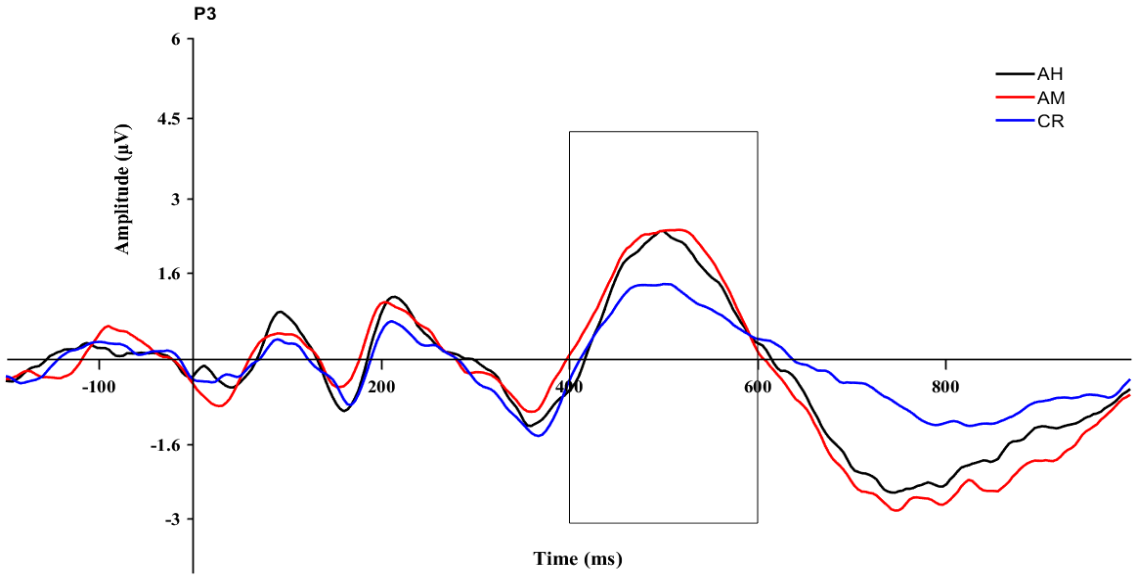

Figure 5B

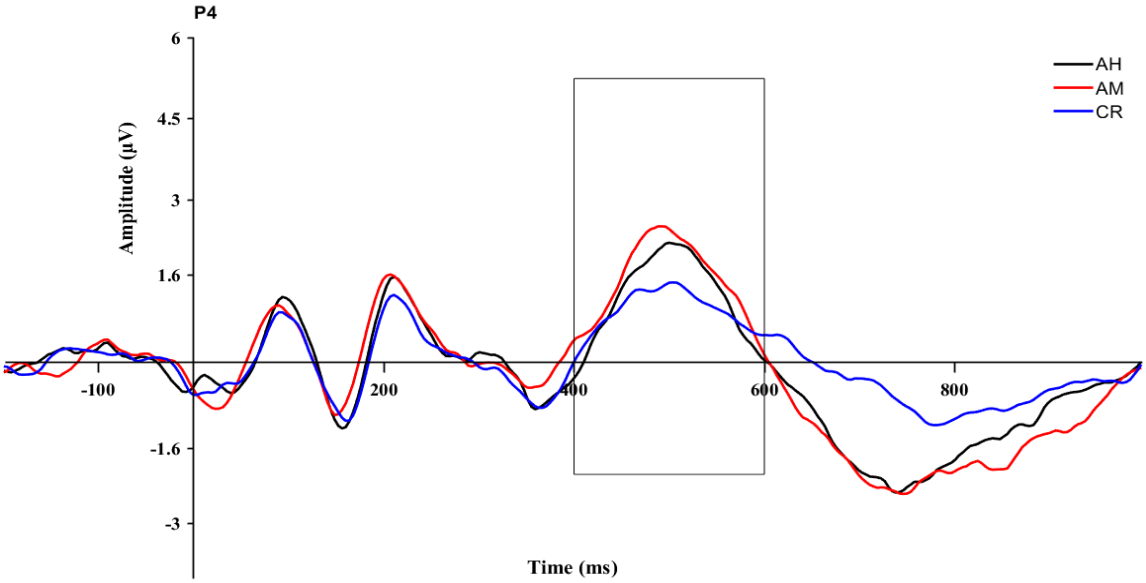

Figure 5. P300 ERP waveforms of ERP conditions for 36 participants at P3 (Panel A) and P4 (Panel B) within latency intervals of 400 – 600 ms. (AH = associative hits; black line. AM = associative misses; red line. CR = correct rejections; blue line.) AH and AM have greater amplitude than CR with AM being the greatest.

Results showed that ERP conditions at F3 were not significantly different, (F(2, 70) = 2.06, p = .14, η_p^2 = 0.056). However, ERP conditions at F4 were statistically different, F(2, 70) = 3.47, p = .04, η_p^2 = 0.090. Post-hoc analysis showed that AH–CR was significant, M = 0.57, SE = 0.22, p = .03, but AH–AM (M = 0.40, SE = 0.25, p = .39) and AM–CR (M = 0.18, SE = 0.19, p > .99) were not significant. See Figure 6.

Figure 6A

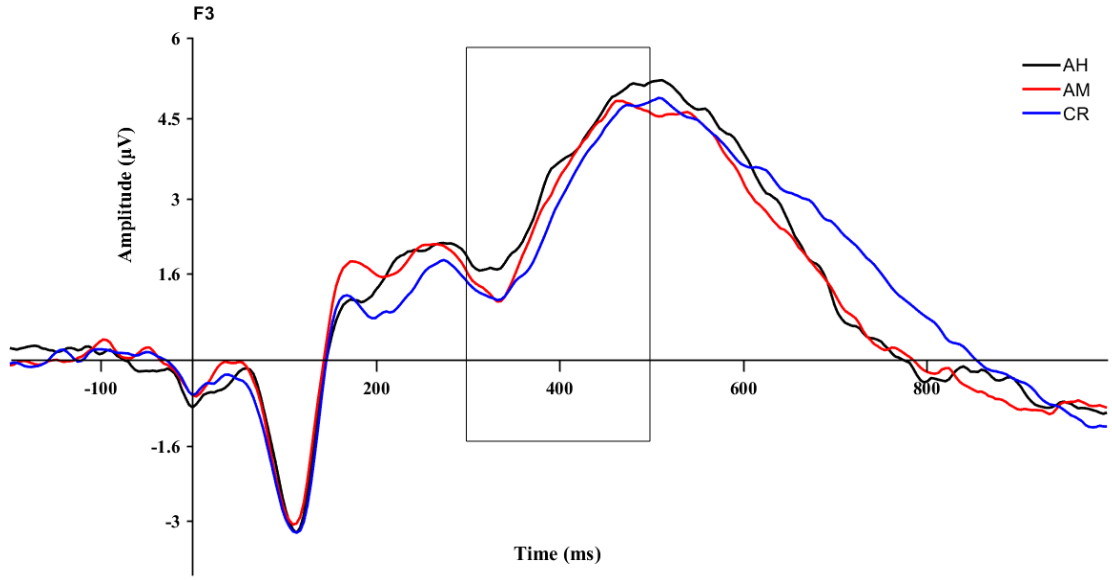

Figure 6B

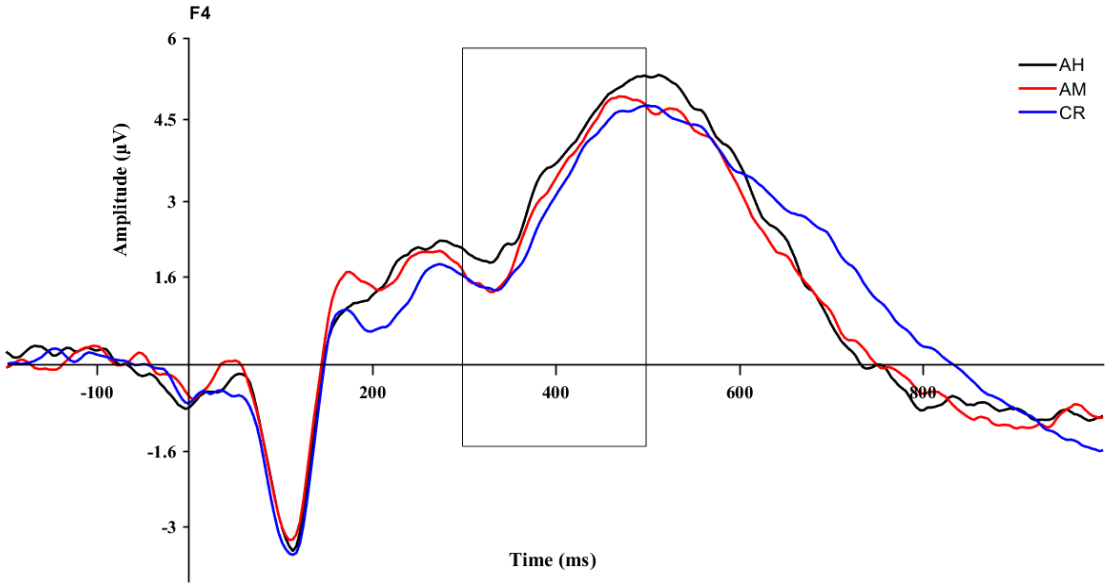

Figure 6. FN400 ERP waveforms of ERP conditions for 36 participants at F3 (Panel A) and F4 (Panel B) within latency intervals of 300 – 500 ms. (AH = associative hits; black line. AM = associative misses; red line. CR = correct rejections; blue line.) AH and AM have greater amplitude than CR with AH being the greatest.

Loneliness Groups and ERP Conditions at P3 and P4

Two 3 × 2 mixed ANOVAs (ERPs: AH, AM, CR × Lonely groups: Less Lonely, More Lonely) were conducted to determine the ERP differences between AH, AM, and CR in the parietal left and right electrode sites over the 400 – 600 ms latency intervals. A two-way mixed ANOVA revealed no significant main effect of ERP conditions at P3, $F(2, 40) = 2.42$, $p = .10$, $\eta_p^2 = 0.11$. No significant interaction effect between the levels of loneliness and the ERP conditions was observed, $F(2, 40) = 0.32$, $p = .73$, $\eta_p^2 = 0.016$. The main effect of lonely groups was also not significant at P3, $F(1, 20) = .35$, $p = .56$, $\eta_p^2 = 0.017$. See Figure 7.

Figure 7A

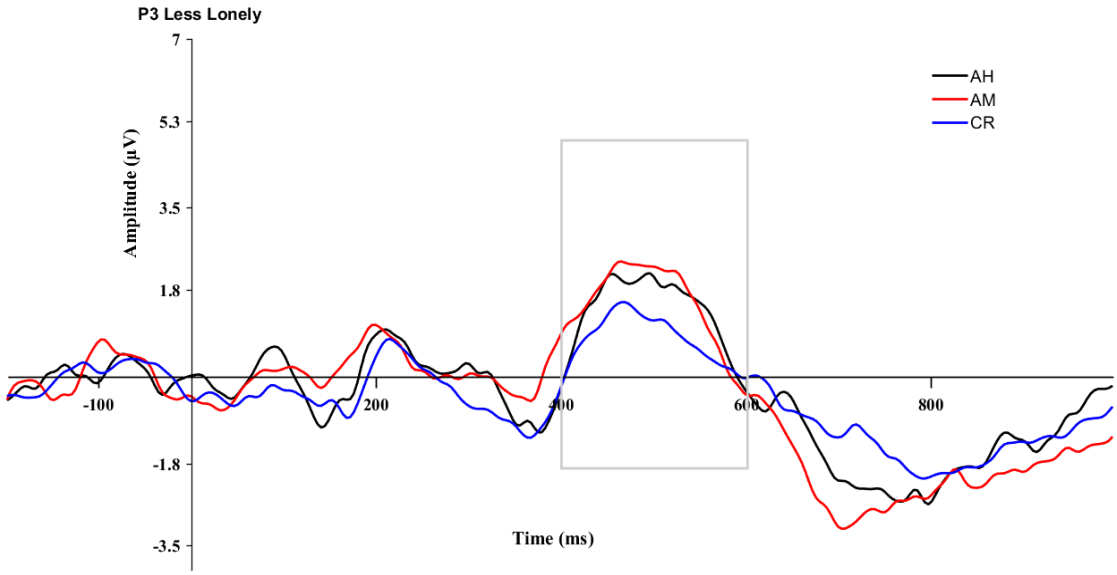

Figure 7B

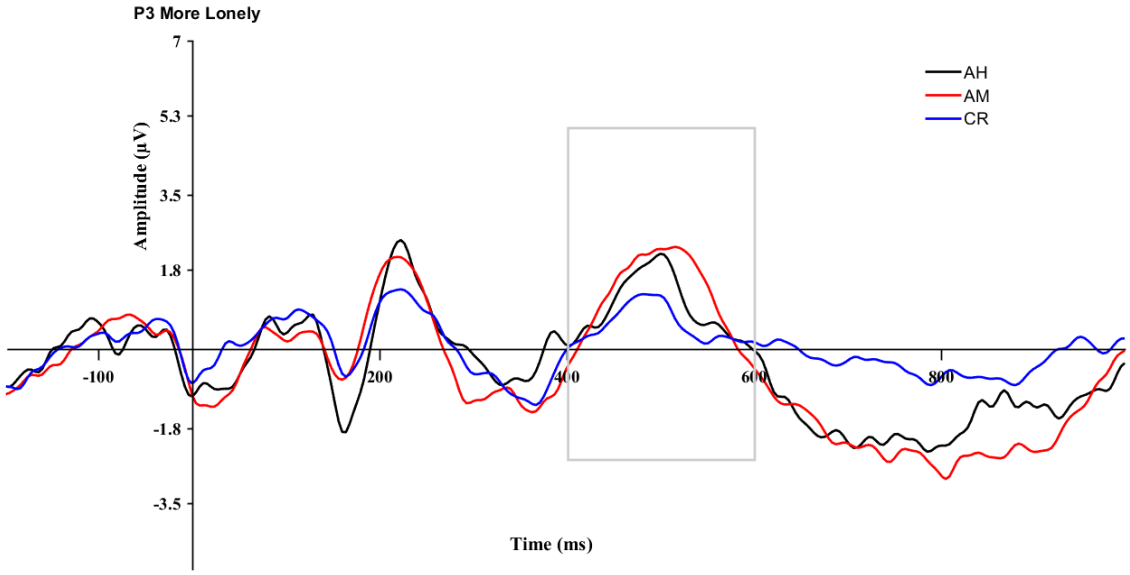

Figure 7. P300 ERP waveforms of both less lonely (Panel A) and more lonely (Panel B) groups within the latency interval of 400 – 600 ms at P3. (AH = associative hits; black line. AM = associative misses; red line. CR = correct rejections; blue line.)

Another two-way mixed ANOVA for P4 revealed that there was no significant main effect of ERP conditions at P4, $F(2, 40) = 1.34$, $p = .28$, $\eta_p^2 = 0.063$. No significant interaction between the levels of loneliness and the ERP conditions was observed, $F(2, 40) = 0.42$, $p = .66$, $\eta_p^2 = 0.021$. The main effect of lonely groups was also not significant, $F(1, 20) = 0.0038$, $p = .95$, $\eta_p^2 < 0.001$. See Figure 8.

Figure 8A

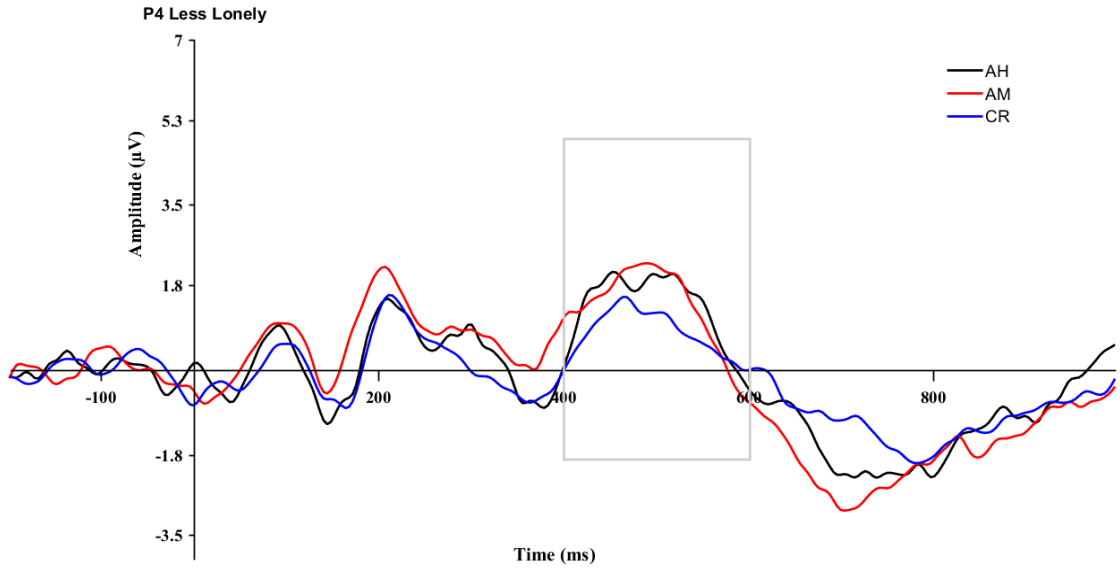

Figure 8B

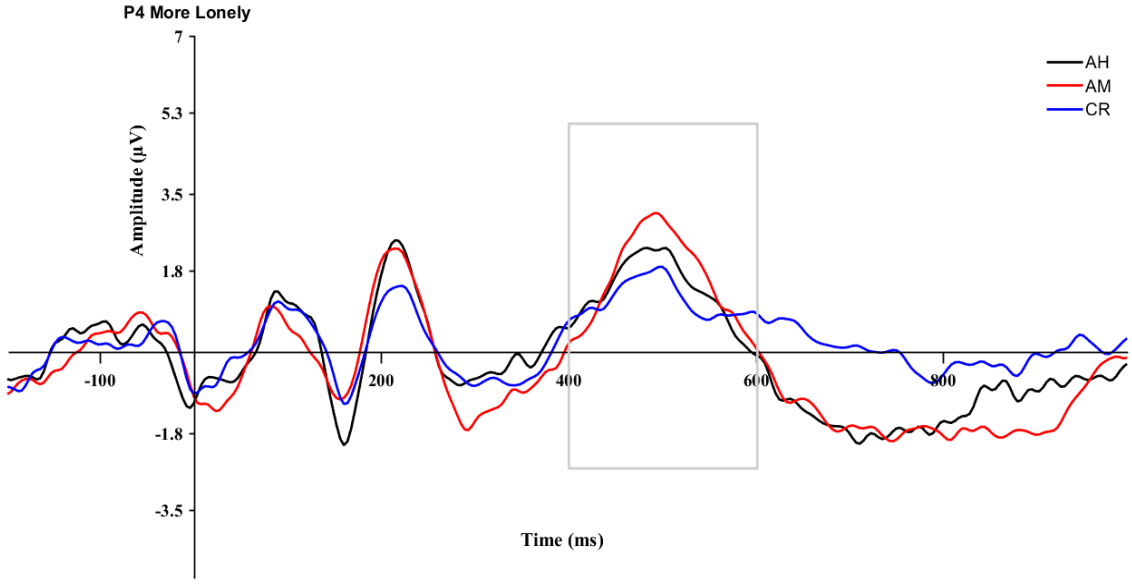

Figure 8. P300 ERP waveforms of both less lonely (Panel A) and more lonely (Panel B) groups within the latency interval of 400 – 600 ms at P4. (AH = associative hits; black line. AM = associative misses; red line. CR = correct rejections; blue line.)

Loneliness Groups and ERP Conditions at F3 and F4

Two 3 × 2 mixed ANOVAs (ERPs: AH, AM, CR × Lonely groups: Less Lonely, More Lonely) were conducted to determine the ERP differences between AH, AM, and CR in the frontal left and right electrode sites over the 300 – 500 ms latency intervals. A two-way mixed ANOVA revealed no significant main effect of ERP conditions at F3, $F(2, 40) = 1.74$, $p = .19$, $\eta_p^2 = 0.080$. No significant interaction effect between the levels of loneliness and ERP conditions was observed, $F(2, 40) = 1.10$, $p = .34$, $\eta_p^2 = 0.052$. There was also no significant main effect of lonely groups, $F(1, 20) = 0.0076$, $p = .93$, $\eta_p^2 < 0.001$. See Figure 9.

Figure 9A

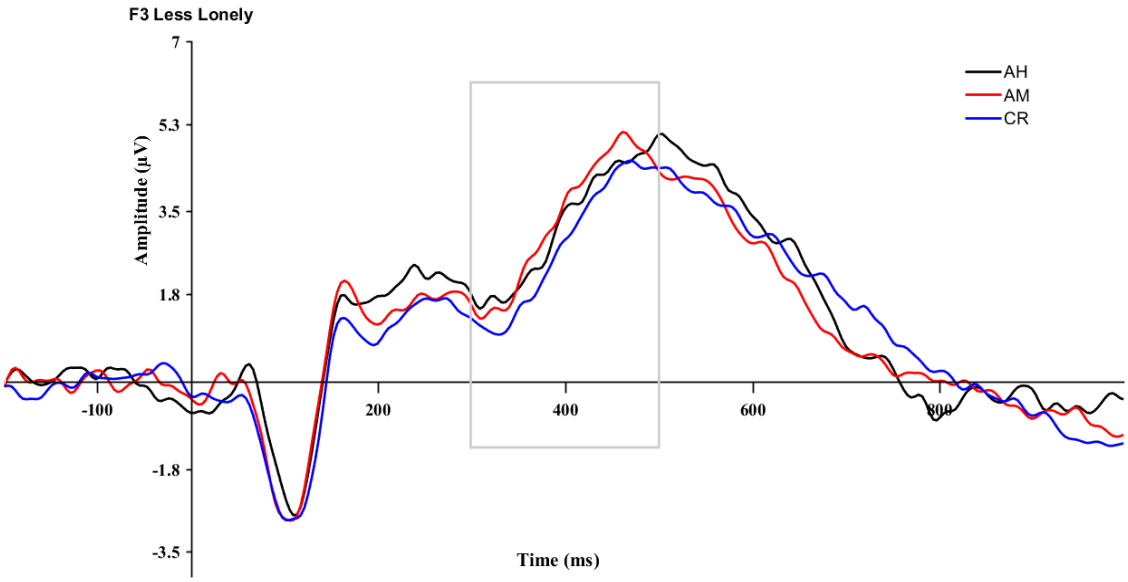

Figure 9B

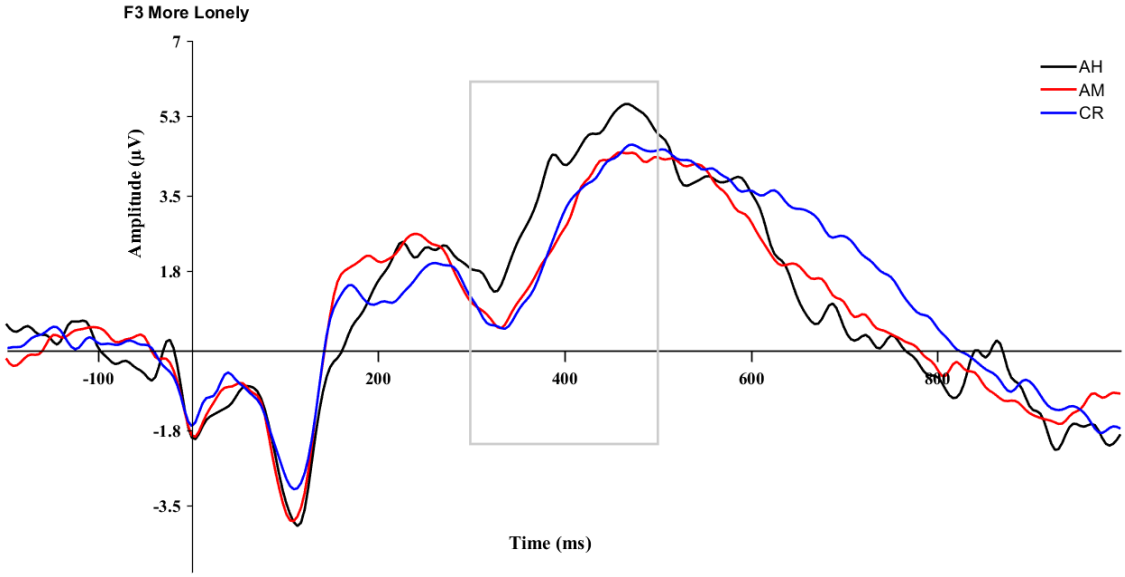

Figure 9. FN400 ERP waveforms of both less lonely (Panel A) and more lonely (Panel B) groups within the latency interval of 300 – 500 ms at F3. (AH = associative hits; black line. AM = associative misses; red line. CR = correct rejections; blue line.)

Another two-way mixed ANOVA revealed that there was a significant main effect of ERP conditions at F4, $F(2, 40) = 3.58$, $p = .037$, $\eta_p^2 = 0.15$. Further analysis revealed that AH–CR was significant, $M = 0.80$, $SE = 0.30$, $p = .046$. The ERP effects for AH–AM ($M = 0\ .53$, $SE = 0.35$, $p = .45$) and AM–CR ($M = 0.27$, $SE = 0.25$, $p = .86$) were not significantly different. There was also no significant interaction effect between loneliness group and ERP conditions at F4, $F(2, 40) = 0.40$, $p = .68$, $\eta_p^2 = 0.019$. However, the main effect of lonely groups was not significant at F4, $F(1, 20) = 0.24$, $p = .63$, $\eta_p^2 = 0.012$. See Figure 10.

Figure 10A

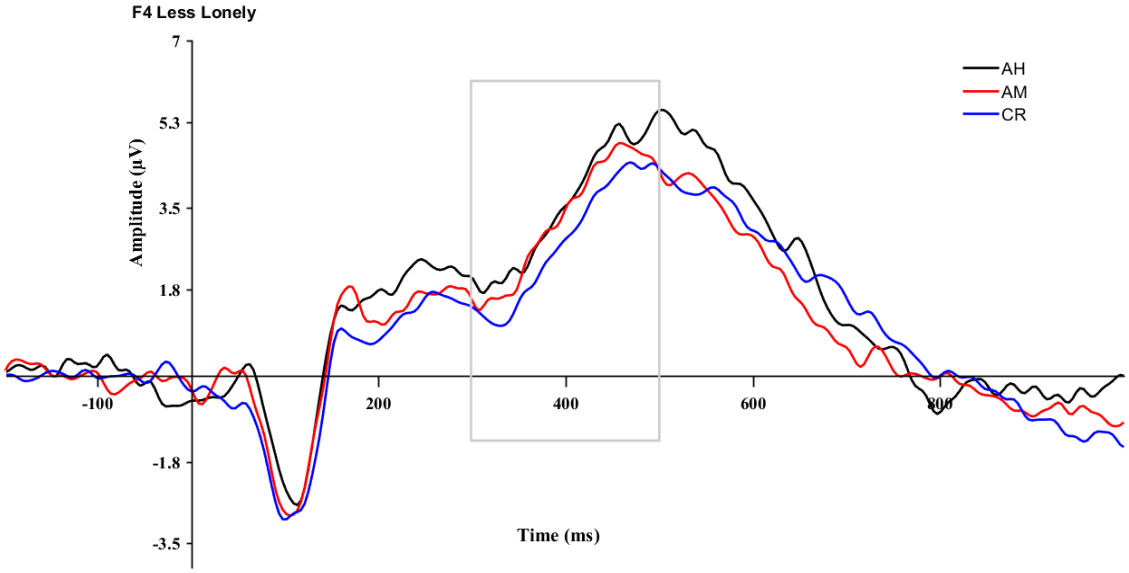

Figure 10B

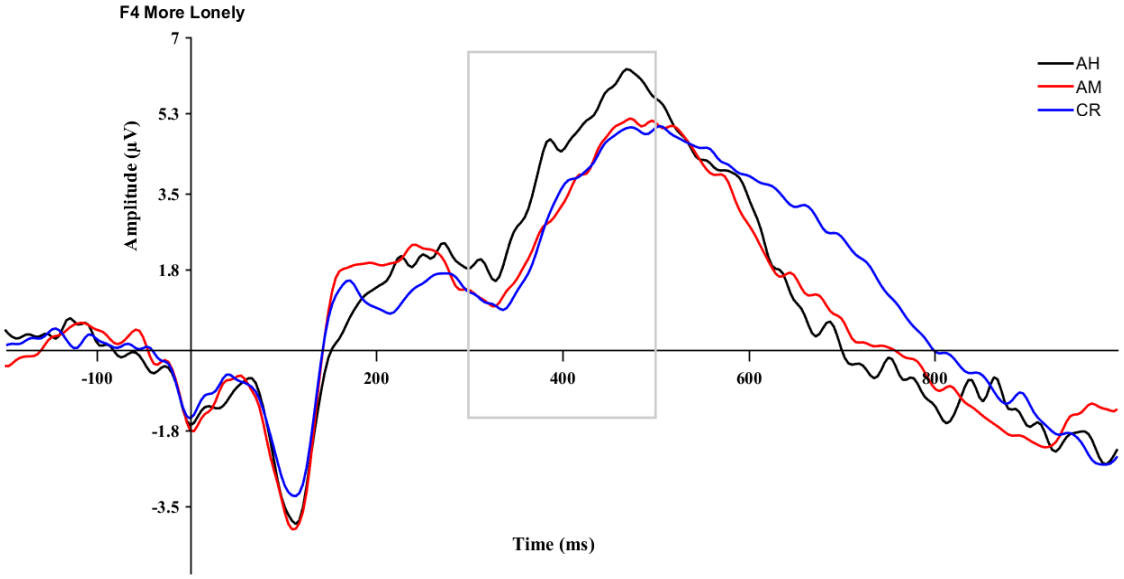

Figure 10. FN400 ERP waveforms of less lonely (Panel A) and more lonely (Panel B) groups within the latency interval of 300 – 500 ms at F4. (AH = associative hits; black line. AM = associative misses; red line. CR = correct rejections; blue line.)

Loneliness, ERP Conditions, and Covariates at P3, P4, F3, and F4

The covariates—depression, trait anxiety, and perceived stress—were included in a secondary analysis to determine if loneliness had a unique relationship with memory performance (ERPs: AH, AM, CR × Lonely groups: Less Lonely, More Lonely; CV: depression, anxiety, stress). The ANCOVA showed only a significant main effect of ERP condition at P3, $F(2, 34) = 4.48$, $p = .019$, $\eta_p^2 = 0.21$. Further analysis showed a significant difference between AM and CR ($M = 0.95$, $SE = 0.25$, $p = .004$, but showed no significant difference between AH and CR ($M = 0.33$, $SE = 0.42$, $p > .99$) and AH and AM ($M = -0.62$, $SE = 0.36$, $p = .30$). There was no significant interaction between lonely groups and ERP conditions or main effect of lonely groups at P3. Another ANCOVA showed no significant main effect on ERP conditions or lonely groups. There was also no significant interaction between lonely groups and ERP conditions at P4. However, the covariate, anxiety, was significantly related to the averaged ERP scores at P4, $F(1, 17) = 5.26$, $p = .035$, $\eta_p^2 = 0.24$, which was not related to ERP memory effects.

The ANCOVA at F3 showed no significant main effect on ERP conditions or lonely groups. There was also no significant interaction between lonely groups and ERP conditions at F3. The covariates, anxiety ($F(1, 17) = 20.13$, $p < .001$, $\eta_p^2 = 0.54$) and stress ($F(1, 17) = 10.29$, $p = .005$, $\eta_p^2 = .38$), were significantly related to ERP mean scores at F3, which was not related to ERP memory effects. The fourth ANCOVA at F4 also showed no significant main effect on ERP conditions or lonely groups. There was also no significant interaction between lonely groups and ERP conditions at F4. The

covariates, anxiety ($F(1, 17) = 24.95$, $p < .001$, $\eta_p^2 = 0.60$) and stress ($F(1, 17) = 14.70$, $p = .001$, $\eta_p^2 = 0.46$), were also significantly related to the averaged ERP scores at F4, which was not related to ERP memory effects.

Exploratory Analysis

It was believed that running the planned analysis did not sufficiently test the current study's hypotheses for two reasons. First, the current study had a small sample size of 22 participants (less lonely, $n = 13$; more lonely, $n = 9$). Second, the behavioral data showed that participants had low accuracy for the proportion of correctly identified colored backgrounds, which suggested that participants were guessing. Guesses are not reflective of recollection. Therefore, exploratory analyses were conducted to further investigate the relationships between loneliness and memory.

The exploratory analyses included data for all 36 participants to increase the sample size. Increasing the sample size provided a more representative sample that may improve the reliability of behavioral (*d'* and proportion of correctly identified colored background) and EEG results (ERP mean averages for AH, AM, and CR). The ERP mean scores for AH and AM were also combined to obtain "Old" scores, which was used to investigate the old-new effect, reflective of general recognition memory. Obtaining the composite recognition memory scores ((AH+AM)/2) to investigate the old-new effect for Old–CR (the difference of composite recognition memory scores and correct rejection) could address the low accuracy of AHs observed in the behavioral planned analysis. Low accuracy of AHs could have been AMs if responses were guesses. The exploratory

analyses included correlations and hierarchical regression. Correlations were used to test relationships between behavioral and ERP effects, using ERP difference scores. Hierarchical regressions were used to test predictive influences of loneliness and covariates on ERP old-new effects.

Behavioral Task Exploratory Results

Correlational analyses were conducted to determine the relationship between loneliness, behavioral recognition memory variables, and the covariates. Results showed that loneliness was not significantly related to *d'*, $r(34) = -.081$, $p = .64$, or the proportion of correctly identified backgrounds, $r(34) = -.11$, $p = .52$. Furthermore, *d'* scores and the proportion of correctly identified backgrounds did not show a statistically significant relationship with the other covariates—depression, anxiety, and stress. The behavioral data results suggest that loneliness was neither predictive of recognition memory nor recollection. No further analysis using hierarchical regression was conducted. Correlations of the variables were presented in Table 2.

Table 2.

Descriptive Statistics and Correlations for Variables in Behavioral Exploratory Analysis

Variable	M	SD	1	2	3	4	5	6
1. Loneliness	41.08	11.82	1.00					
2. Depression	5.09	0.78	.71***	1.00				
3. Anxiety	45.17	12.67	.75***	.84***	1.00			
4. Stress	19.83	7.24	.71***	.79***	.87***	1.00		
5. d'	3.12	0.67	-.081	-.24	-.14	-.081	1.00	
6. Proportion of AH	0.42	.096	-.11	-.017	-.040	.004	.12	1.00

*$p < .05$. ***$p < .001$.

Other correlational analyses were conducted to determine the relationship between behavioral recognition memory variables and ERP recognition memory effects using difference scores (i.e., AH–CR, AM–CR, AH–AM, Old–CR). The ERP recognition memory effects at all four electrode sites showed a weak relationship with *d'* that was not statistically significant. The ERP recognition memory effects at all four electrode sites generally showed a weak negative relationship with the proportion of correctly identified color background, and many of these relationships were not statistically significant. It was noted that there were statistically significant relationships with AH–CR at P4, $r(34) = -.37$, $p = .029$, and F4, $r(34) = -.36$, $p = .030$. Old–CR at P3, $r(34) = -.35$, $p = .036$, and P4, $r(34) = -.41$, $p = .014$, were statistically significant. A statistically weak negative relationship was observed with AH–AM at F4, $r(34) = -.37$, $p = .025$.

Electroencephalography Exploratory Results

A correlation was conducted to determine the relationship between loneliness, ERP recognition memory effects (i.e., AH–CR, AM–CR, AH–AM, Old–CR) at parietal (P3, P4) and mid-frontal (F3, F4) electrode sites, and the covariates. Following that, hierarchical regression analyses were conducted for electrode sites that explored significant correlations with the ERP recognition memory effects and loneliness with the covariates depression, trait anxiety, and stress.

Correlation Analyses at P3, P4, F3, and F4. Correlation results at P3 showed that loneliness was not significantly correlated with AH–CR, $r(34) = -.24$, $p = .17$ or AH–AM, $r(34) = .040$, $p = .082$. A trend was observed with AM–CR at P3, $r(34) = -.32$, $p = .057$. However, a statistically significant weak negative relationship between loneliness and Old–CR at P3 was found, $r(34) = -.33$, $p = .047$. Correlation results between loneliness and ERP recognition memory effects at P4, F3, and F4 showed no statistically significant correlations. Correlations for the variables at all electrode sites were presented in Table 3.

Table 3.

Correlations in Exploratory Analysis for Loneliness by ERP Conditions at Electrode sites

Variable	AH–CR	AM–CR	AH–AM	Old–CR
P3	-.24	-.32	.040	-.33*
P4	-.19	-.27	.027	-.27
F3	.025	-.25	.22	-.13
F4	.037	-.15	.15	.10

*$p < .05$.

Hierarchical Regression Analysis. Further analyses using hierarchical regression models were used to investigate ERP old-new effects at P3. In a hierarchical regression, the Old–CR was the criterion variable and the predictor variables were loneliness, depression, anxiety, and stress. Depression, anxiety, and stress were analyzed in the first step and loneliness was added in the second step. Results in step one indicated that the model was not statistically significant, $R^2 = .054$, $F(3, 32) = 0.61$, $p = .62$. Depression ($\beta = -.013$), anxiety ($\beta = -.056$), and stress ($\beta = -.17$) were not predictive of Old–CR at P3. Step two showed that loneliness did not statistically predict significant relationship with Old–CR at P3, $\Delta R^2 = .064$, $\Delta F(1, 31) = 2.23$, $p = .15$, with loneliness alone accounting for 11% variance to the model (see Figure 11). This result showed that loneliness was most predictive among the predictors in the second model ($sr^2 = .064$) in comparison to the other predictors, which each accounted for less than 0.27% of the variance observed in the ERP recognition memory effect. See Table 4. ERP waveform for Old and CR is

shown in Figure 12.

Table 4.

Hierarchical Regression Results for ERP Parietal Old-New Effect at P3

Variable	B	95% CI for B		*SE* B	β	R^2	ΔR^2	r^2	sr^2
		LL	*UL*						
Step 1						.054	.054		
Depression	-.021	-1.07	1.03	.51	-.013			.038	< .001
Anxiety	-.005	-0.07	0.073	.039	-.056			.046	< .001
Stress	-.029	-0.15	0.093	.060	-.17			.053	.007
Step 2						.12	.064		
Depression	.12	-.93	1.17	.51	.078			.038	.0016
Anxiety	.011	-0.070	0.091	.040	.11			.046	.0020
Stress	-.018	-0.14	0.10	.059	-.11			.053	.0027
Loneliness	-.041	-0.097	0.015	.028	-.39			.11	.064

*$p < .05$.

Figure 11

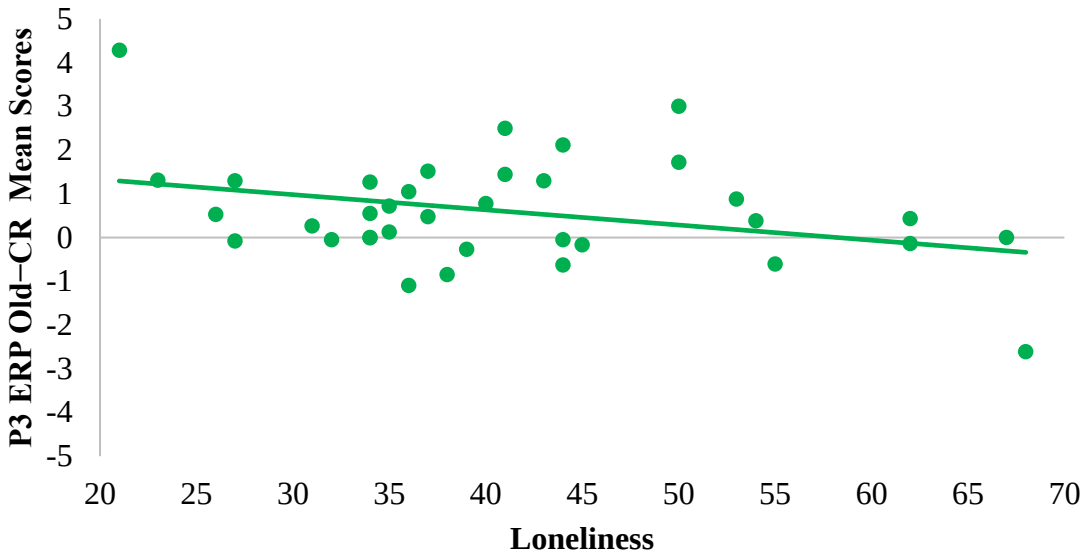

Figure 11. A weak negative relationship between loneliness and ERP old-new recognition memory effect at the left parietal electrode site (P3).

Figure 12

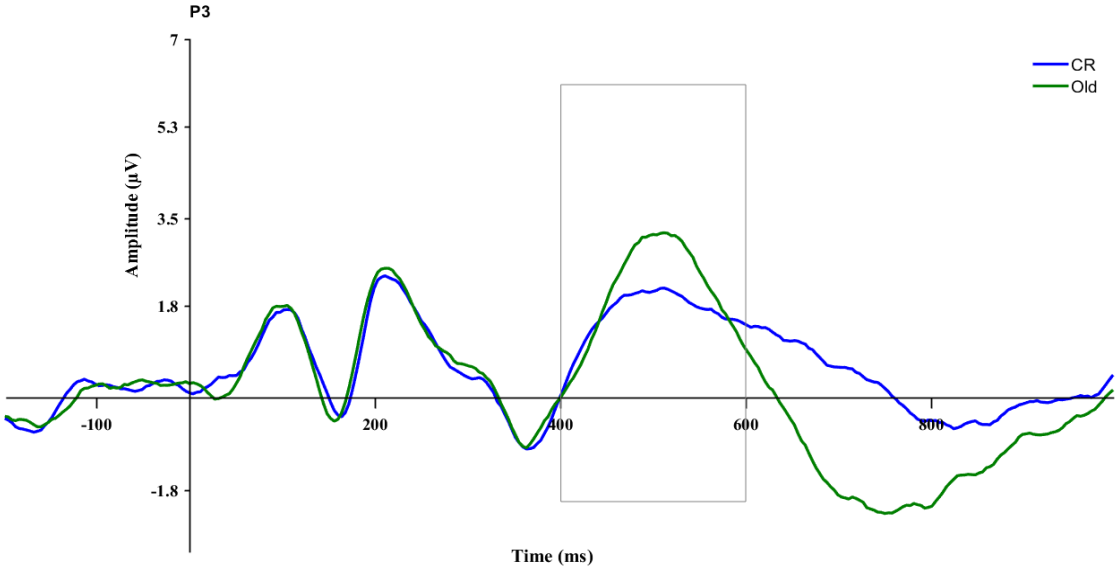

Figure 12. P300 ERP waveforms of Old and CR for 36 participants at P3 within latency intervals of 400 – 600 ms. (CR = correct rejections; blue line, Old = average of AH and AM; green line). Old has greater amplitude than CR showing ERP parietal old-new effect at P3.

DISCUSSION

The current study examined the relationship between loneliness and recognition memory. Specifically, the study tested the hypothesis that more lonely individuals would have a poorer overall recognition memory with lower recollection compared to less lonely individuals. In addition, more lonely individuals would have lower ERP parietal old-new effects, but no difference in ERP mid-frontal old-new effects than less lonely individuals. The results from the planned and exploratory analyses did not support that more lonely individuals would have poorer recognition memory and recollection than less lonely individuals. The planned analysis also did not support that lonelier individuals had smaller ERP parietal old-new effects in comparison to less lonely individuals. Consistent with the hypothesis, results showed no difference in ERP mid-frontal old-new effects among the loneliness groups. However, the results of the exploratory analysis showed that there is a difference between loneliness for ERP parietal old-new effects. Ultimately, the current study's findings should be interpreted cautiously.

Behavioral Task Discussion

Contrary to the hypothesis, the planned analyses revealed that loneliness groups did not statistically differ in *d'* scores nor the proportion of correctly identified color backgrounds. Furthermore, the exploratory analyses also showed no significant relationship between loneliness scores with behavioral data. The behavioral results indicated that recognition memory and recollection did not differ with loneliness. These

results were not consistent with previous research that has shown that loneliness negatively impacts cognitive functions, including memory (Boss et al., 2015; Xu et al., 2018). Past research, however, has focused on the impact loneliness had on semantic and working memory, which could have different results from recognition memory (Xu et al., 2018). Additionally, many of the loneliness and memory research has focused on older adults, who may tend to develop memory deficits due to their age (Wilson et al., 2007). Loneliness could have exacerbated memory deficits in older adults than in younger adults. Loneliness may not have a significant direct impact on recognition and recollection memory with younger individuals.

Electroencephalography Discussion

The ANOVAs investigating the ERP old-new effects revealed a significant parietal old-new effect with greater ERPs between associative misses and correct rejections at P3, but not at P4. The significant parietal old-new effect at P3 partially supported past research in that the parietal old-new effect was more prominent on the left electrode site during memory performance (Curran, 2004). Although a difference was observed between associative misses and correct rejections in the present study, past research has shown that the greatest amplitude differences had been between associative hits and correct rejections and between associative hits and associative misses that are representative of recollection (Jaeger & Parente, 2008; Rugg & Curran, 2007). The present results also revealed a significant mid-frontal old-new effect at F4 with greater ERPs for associative hits vs. correct rejections but not with the other ERP conditions.

ERP effects were not significant at F3. Since there was no significant amplitude difference between AHs and AMs, there is a possibility that a familiarity-related ERP effect was observed (Curran, 2000).

However, EEG results showed no significant interaction between loneliness groups and ERP parietal and mid-frontal old-new effects at their respective left and right electrode sites even when the covariates were included, indicating that loneliness was not related to recollection or familiarity. This lack of modulation in the various ERP conditions suggested that loneliness may not have a significant direct impact on ERP effects associated with recognition memory. ERPs did not support the hypothesis that there would be a significant effect at the parietal sites with greater effects on the left parietal site. It also did not reflect results of past research that memory for contextual detail should display an observable difference at the parietal sites, prominently in the left parietal electrode site, with ERP AH amplitudes being greater than both AM and CR (Curran, 2004; Noh et al., 2018). The current study's results may suggest that background color was not a relatable contextual detail to the images as supported by the low accuracy in correctly identifying the color background. A lack of relation of context to item may not ensure a stronger memory formation, thus a generally lower recollection memory.

However, the results partially supported the hypothesis that there would be no difference in ERP mid-frontal old-new effects between loneliness groups, which suggests that familiarity was retained in both groups. There are no specific past studies that have investigated this, but a depression study had shown that depressed individuals retained

similar familiarity abilities to non-depressed counterparts (Dillon & Pizzagalli, 2018). It may be evident that identifying old and new images from the memory task was too easy and identifying the color backgrounds was too difficult, which could have resulted in a ceiling and a floor effect, respectively. Although results showed that familiarity was similar in both lonely groups, the results suggested that ERP memory non-specific effects varied by anxiety and stress scores at the mid-frontal sites. These results may relate to attention to the task (Cacioppo & Cacioppo, 2016). Further exploration is needed to explain the interplay between loneliness, anxiety, stress, memory, and attention.

Exploratory Analyses' Discussion

Exploratory analyses further explored the study's hypotheses and revealed that the behavioral data (i.e., *d'* scores, the proportion of correctly identified colored background) were not significantly correlated with loneliness, supported the planned analyses' results in that loneliness may not negatively impact memory performances. Correlational analyses also showed that *d'* scores were not correlated with the ERP effects, but the proportion of correctly identified color backgrounds was correlated with some of the ERP effects at P3, P4, and F4. There is evidence that the proportion of correctly identified color backgrounds was representative of recollection (Jaeger & Parente, 2008; Rugg & Curran, 2007), but other researchers did not find a correlation with the magnitude of ERP old-new effects and memory performance as noted in a two-experiment study (MacLeod & Donaldson, 2017) A possible explanation could be that proportion of Hit and CR responses may not sufficiently characterize the ERP difference, specifically the parietal

old-new effects. There could be a variability of remembered information as individuals may use different encoding methods or the tasks may engage recollection differently (MacLeod & Donaldson, 2017). Another possible reason could be that guesses in the memory task could have reduced any observable effects.

The exploratory analyses involving all 36 participants also indicated a significantly weak negative correlation with loneliness and old-new effect at the left parietal electrode site, suggesting a possible negative relationship between loneliness and ERP recognition memory effect. This result aligns with the direction of the hypotheses that lonelier individuals would have lower ERP recognition memory effects. Lonely individuals may process information differently from their peers, even if memory performance is similar. Loneliness may impact memory declination (Boss et al., 2015; Jaremka et al., 2014; Wilson et al., 2007), but may not necessarily significantly impact recollection memory. The hierarchical regression, however, showed evidence that loneliness may provide a better explanation for recognition memory deficits than depression, stress, or anxiety, especially at P3. Consistent with past research, results indicated that loneliness, although related, is differentiable from depression, anxiety, and stress (Cacioppo et al., 2006a; Cacioppo et al., 2014). Loneliness alone may have a negative influence on ERP recognition memory effects, but future research is needed to confirm this finding.

Limitation and Future Research

Several notable limitations should be considered when interpreting the findings. One major limitation that affected the results of the current study was the low sample size. With this study being an EEG study on loneliness, many exclusion criteria limited recruitment. The study also selected individuals who scored one-half SD above and below the mean in the UCLA Loneliness Scale, thereby limiting the number of participants in each loneliness group. Additionally, participation in this study was discontinued abruptly due to the COVID-19 pandemic, which prevented further data collection to increase the sample size.

In addition to the small sample size, participants in the current study generally had a low proportion of correctly identified colored backgrounds, whether they were considered less or more lonely. The low scores could have suggested a floor effect in the associative memory task, with the retrieval of background color being too difficult for individuals. Increasing the duration a stimulus would be presented and the response time to two or three seconds may have improved behavioral scores. With the low behavioral data scores, participants may have been guessing throughout the memory task as noted by the difficulty in distinguishing ERPs for AH and AM with AH being guesses rather than true recollection. Therefore, further research could record the participant's confidence in each response to ensure that participants were not guessing throughout the task.

Furthermore, the current study's associative memory task required participants to recognize both items and their associated color backgrounds while trying not to blink or

move. Requiring the participants to minimize blinking while performing an ERP memory task may take considerable mental effort (Luck, 2014). Not saying anything about blinking to the participants may have yielded larger P300 ERP component differences (Ochao & Polich, 2000. as cited in Luck, 2014) and better retrieval of old stimuli and their associated background colors. It could be possible that these participants generally had poor memory.

There are a few limitations that are specific to EEG data and analyses. First, most of the raw data of each participant consisted of electrical noise and facial artifacts within the epochs as well as high impedance. Although many of these artifacts were corrected using ICA before artifact detection, ICA could have overcorrected or distorted the ERP waveforms as a relatively smaller number of recording electrodes were used in this study. Using ICA or having noisy data, which was prominent in this current study, could have impacted the observed results. There is no good substitute for obtaining good data, as noted by Luck (2014). Lowering the humidity and temperature of the room during data collection could have improved impedance. Therefore, it is important to create an environment that is comfortable for individuals participating in the study. Future studies could improve by including more breaks or providing snacks during breaks to reduce artifactual potentials generated by eye and muscle movements during stimulus presentation.

The current study focused on the P300 and FN400 ERP components at the parietal and mid-frontal regions, respectively, that are commonly associated with memory

research. However, the possibility of other overlapping ERP components could have impacted the memory effects. As noted above, the LPN component often overlaps with the latency interval of P300 component (Mecklinger et al., 2016). Future research could focus on the interaction between loneliness and LPN memory effects. Other research could use stimuli that initiates stronger P300 effects while limiting LPN effects when investigating memory and loneliness.

In addition to improving the current study, future research could observe reaction times for recollection and familiarity as it has been noted that these retrieval processes differ in speed. It could also investigate the encoding behavioral and ERP data to observe if participants were paying attention during the encoding phase and if there were underlying ERP differences between the encoding and retrieval process that influenced loneliness-related memory performance. The encoding phase would also provide some evidence to whether recollection and familiarity will be observed, which will ensure a comprehensive understanding of the impact loneliness has on the retrieval processes of recognition memory.

CONCLUSION

Results did not indicate that loneliness negatively related to recognition memory as no interactions between behavioral and ERP recognition memory and loneliness were found. There is, however, evidence that loneliness alone may negatively impact recognition memory as shown in the EEG exploratory results. Furthermore, there are observable trends at the left parietal electrode sites showing loneliness may negatively impact ERP recollection memory effects, but not ERP familiarity memory effects. By improving the methodology of the study and increasing sample size, a more conclusive result could enlighten the possible impact, or the lack thereof, loneliness has on memory. Therefore, future studies may provide effective assessment on lonely individuals and provide effective electrophysiological interventions that can improve both perceptions of social isolation and memory performance, especially with vulnerable populations such as college students, older adults, or individuals experiencing sudden life-changing events.

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APPENDIX A

Revised UCLA Loneliness Scale

Instructions: Indicate how often each of the statements below describes you.

1.	**I feel in tune with the people around me.** *			
	1	2	3	4
	Never	Rarely	Sometimes	Often
2.	**I lack companionship.**			
	1	2	3	4
	Never	Rarely	Sometimes	Often
3.	**There is no one I can turn to.**			
	1	2	3	4
	Never	Rarely	Sometimes	Often
4.	**I do not feel alone.**			
	1	2	3	4
	Never	Rarely	Sometimes	Often
5.	**I feel part of a group of friends.** *			
	1	2	3	4
	Never	Rarely	Sometimes	Often
6.	**I have a lot in common with the people around me.** *			
	1	2	3	4
	Never	Rarely	Sometimes	Often
7.	**I am no longer close to anyone.**			
	1	2	3	4
	Never	Rarely	Sometimes	Often
8.	**My interests and ideas are not shared by those around me.**			
	1	2	3	4
	Never	Rarely	Sometimes	Often
9.	**I am an outgoing person.** *			
	1	2	3	4
	Never	Rarely	Sometimes	Often

10. There are people I feel close to. *

1	2	3	4
Never	Rarely	Sometimes	Often

11. I feel left out.

1	2	3	4
Never	Rarely	Sometimes	Often

12. My social relationships are superficial.

1	2	3	4
Never	Rarely	Sometimes	Often

13. No one really knows me well.

1	2	3	4
Never	Rarely	Sometimes	Often

14. I feel isolated from others.

1	2	3	4
Never	Rarely	Sometimes	Often

15. I can find companionship when I want it. *

1	2	3	4
Never	Rarely	Sometimes	Often

16. There are people who really understand me. *

1	2	3	4
Never	Rarely	Sometimes	Often

17. I am unhappy being so withdrawn.

1	2	3	4
Never	Rarely	Sometimes	Often

18. People are around me but not with me.

1	2	3	4
Never	Rarely	Sometimes	Often

19. There are people I can talk to. *

1	2	3	4
Never	Rarely	Sometimes	Often

20. There are people I can turn to. *

1	2	3	4
Never	Rarely	Sometimes	Often

* Items are reversed-scored.

APPENDIX B

The Center for Epidemiologic Studies Depression Scale Revised

Instructions: Below is a list of the ways you might have felt or behaved. Please choose the option you most agree with to tell me how often you have felt this way in the past week or so.

1. My appetite was poor.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

2. I could not shake the blues.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

3. I had trouble keeping my mind on what I was doing.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

4. I felt depressed.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

5. My sleep was restless.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

6. I felt sad.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

7. I could not get going.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

8. Nothing made me happy.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

9. I felt like a bad person.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

10. I lost interest in my usual activities.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

11. I slept much more than usual.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

12. I felt like I was moving too slowly.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

13. I felt fidgety.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

14. I wished I were dead.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

15. I wanted to hurt myself.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

16. I was tired all the time.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

17. I did not like myself.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

18. I lost a lot of weight without trying to.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

19. I had a lot of trouble getting to sleep.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

20. I could not focus on the important things.

0	1	2	3	4
Not at all or less than 1 day last week.	One or two days last week.	Three to four days last week.	Five to seven days last week.	Nearly every day for 2 weeks.

APPENDIX C

The Trait Anxiety Inventory

Instructions: Please select how often each of the statements people have used to describe you.

1. I feel pleasant. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

2. I feel nervous and restless.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

3. I feel satisfied with myself. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

4. I wish I could be as happy as others seem to be.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

5. I feel like a failure.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

6. I feel rested. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

7. I am "calm, cool, and collected." *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

8. I feel that difficulties are piling up so that I cannot overcome them.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

9. I worry too much over something that really doesn't matter.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

10. I am happy. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

11. I have disturbing thoughts.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

12. I lack self-confidence.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

13. I feel secure. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

14. I make decisions easily. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

15. I feel inadequate.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

16. I am content. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

17. Some unimportant thought runs through my mind and bothers me.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

18. I take disappointments so keenly that I can't put them out of my mind.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

19. I am a steady person. *

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

20. I get in a state of tension or turmoil as I think over my recent concerns and interests.

1	2	3	4
Almost Never	Sometimes	Often	Almost Always

*Items are reversed-scored.

APPENDIX D

Perceived Stress Scale

Instructions: Indicate how often you have felt or thought these certain ways during the last month.

1. Been upset because of something that was happened unexpectedly?

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

2. Felt that you were unable to control the important things in life?

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

3. Felt nervous and "stressed"?

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

4. Felt confident about your ability to handle your personal problems? *

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

5. Felt that things were going your way? *

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

6. Found that you could not cope with all the things that you had to do?

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

7. Been able to control irritations in your life? *

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

8. Felt that you were on top of things? *

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

9. Been angered because of things that were outside of your control?

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

10. Felt difficulties were piling up so high that you could not overcome them?

0	1	2	3	4
Never	Almost Never	Sometimes	Fairly Often	Very Often

*Items are reversed-scored.

APPENDIX E

Demographic Information

Please provide the following information by indicating your answer for each question:

1. **Biological Sex**:
   o Male o Female
2. **Gender**:
   o Man o Woman o Transman
   o Transwoman o Other o Prefer not to answer
3. **Age**:
4. **I would describe my ethnicity as**:
   o Hispanic or Latino o Not Hispanic or Latino
5. **I would describe my race as**:
   o American Indian/Alaskan Native
   o Asian
   o Native Hawaiian or other Pacific islander
   o Black
   o White
   o More than one race
   o Unknown or Not reported
6. **Classification of Year**:
   o Freshman
   o Sophomore
   o Junior
   o Senior
   o Graduate
7. **What is your handedness?**
   o Right-handed o Left-handed

VITA

After completing high school in Malaysia, Carmen attended LeTourneau University at Longview, Texas, and completed her Bachelor of Science in Psychology in May 2018. Carmen continued her education at Stephen F. Austin State University in August 2018, where she received her degree of Master of Arts in General Psychology in August of 2020.

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