Degree project

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The Neural Correlates of Emotional Intelligence: A Systematic Review

Bachelor Degree Project in Cognitive Neuroscience

First Cycle 22.5 credits

Spring term 2023

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Abstract

Emotional intelligence (EI) lies at the intersection of emotion and cognition and is seen as beneficial to our relationships and well-being. Yet, there is a gap in knowledge regarding the neural correlates of EI. There are three prevailing models defining the psychological construct of EI, the trait model, the ability model, and the mixed model. According to the ability model, EI consists of two facets - experiential and strategic EI. Experiential EI refers to abilities of perceiving and using emotions to facilitate thoughts, whereas strategic EI refers to abilities of understanding and managing emotions. This systematic review aims to investigate whether, and to what extent, the neural correlates of experiential and strategic EI rely on similar or different neural substrates. Five peer-reviewed studies met the inclusion criteria and were included. All the studies used Mayer-Salovey-Caruso Emotional Intelligence Test to measure EI. The brain imaging techniques used included structural and functional magnetic resonance imaging and diffusion tensor imaging. The findings of the review suggest that experiential and strategic EI rely partly on distinct and partly on common neural circuitry. Neural correlates associated primarily with strategic EI were gray matter volumes of ventromedial and ventrolateral prefrontal cortex and anterior and posterior insula. Both strategic and experiential EI were found to correlate with the rostral anterior cingulate cortex gray matter activation, and the effective connectivity of the anterior prefrontal cortex. Further research and development of measurement methodology are needed to deepen the understanding of strategic and experiential EI and their neural correlates.

Keywords: emotional intelligence, ability emotional intelligence, strategic emotional intelligence, experiential emotional intelligence, MSCEIT

The Neural Correlates of Emotional Intelligence: A Systematic Review

Emotional Intelligence (EI) has received an increasing amount of attention from the scientific community. As the term implies, EI lies at the intersection of emotion and cognition. EI has been shown to be beneficial to our relationships, and it is closely connected to well-being (Salovey & Mayer, 1990). EI is said to protect against emotional burdens experienced in daily life and the workplace (Bru-Luna et al., 2021). Also, it has been shown that EI helps combat psychological distress by supporting behavioral changes needed to reduce stress and develop resilience (Sanchez-Gomez & Breso, 2020). Further, individuals with high EI are more likely to efficiently use emotional information in problem-solving and goal achievement (Brackett et al., 2011; Jausovec et al., 2001; Miao et al., 2017). In order to improve these capacities, it is important to understand the neural underpinnings of EI. However, there is still a gap in knowledge regarding the neural correlates of EI. Therefore, a closer look at the current state of research in the field is needed.

Affect is an umbrella term for valenced states, such as emotions and moods (Gross, 2015). Ochsner and Gross (2005) define emotions as valenced responses to external stimuli and/or internal mental representations that: 1) are distinct from moods in that they have recognizable triggers; 2) can involve multiple types of appraisal processes; 3) can either be learned or unlearned responses to stimuli; and 4) depend on different neural systems while creating changes across different response systems. Most researchers agree that emotional response includes multiple components, such as a physiological reaction to a stimulus, a behavioral response, and a feeling or the subjective experience of emotion (Sander et al., 2018). In his cognitive appraisal theory of emotion, Lazarus (1991b) suggested that an emotional response is caused by our subjective interpretation and evaluation of the specific situation. This idea is also central to Gross' modal model of emotion in which an emotion is evoked when a person pays attention to a particular situation and interprets this situation as harmful or helpful (Gross, 1998). Still, the question remains whether appraisal, that is, an individual's cognitive valuation of a such state or experience (Gross, 2015), is part of the emotional response as such or simply an antecedent to the emotional response (Sander et al., 2018).

According to Lazarus (1991a), cognition is both a sufficient and necessary condition to evoke an emotion, and emotion cannot occur without a thought. Although it has been appealing to separate emotion from cognition, Damasio (1994) challenged this dualistic view, pointing out that rationality and emotion cannot be separated. According to his somatic marker theory, the emotional evaluation of the consequences of a certain action leads to bodily reactions, so-called somatic markers (Damasio, 1994; Gazzaniga, 2016). Research has shown that brain regions viewed as affective are involved in cognition, and the regions viewed as cognitive are involved in emotion processing, and further that cognition and emotion are integrated in the brain (Dolan, 2002; Dolcos et al., 2011; Drevets & Raichle, 1998; Phelps, 2006). These results indicate a reciprocal effect and bidirectional interaction between cognition and emotion.

Intelligence is commonly defined as an ability related to knowledge, reasoning, decision-making, problem-solving, learning, and adapting to changes (Gazzaniga et al., 2016). Intelligence is considered an umbrella term consisting of different aspects, such as 1) social intelligence, 2) cognitive intelligence, and 3) emotional intelligence (Bar-On et al., 2003). Social intelligence and EI are closely connected since they both refer to adaptive social and emotional behavior. According to Thorndike (1920, as cited in Hedlund & Sternberg, 2000), social intelligence consists of abilities in understanding social situations and behaving wisely in relation to others. Cognitive intelligence in turn refers to general mental ability related to different cognitive processes (Côté & Miners, 2006; Schaie, 2001). EI, on the other hand, is associated with the skill and ability to be aware of and express the emotions of oneself and others, to manage and control those emotions to solve problems (Bar-On et al., 2003). Flynn (2007) mentions that over time when social priorities shift, the demand for different cognitive skills sets the premise for what intelligence could consist of. If "Intelligence is what the tests test" (Boring, 1923, p. 35, as cited in Neisser, 1979), perhaps a degree of performance on the empirically derived measures combining all the relevant dimensions could define intelligence (Neisser, 1979).

It has been shown that cognitive intelligence is more reliant on the prefrontal cortex (PFC) and the other cortical structures that support logical reasoning whereas social intelligence and EI are more dependent on the limbic neural systems involved in emotional processing and social cognition (Bar-On et al., 2003; Pessoa, 2008). Despite the seemingly independent neural correlates underlying these constructs of intelligence, it has been suggested that an overlap between these neural circuitries could potentially exist (Wranik et al., 2007). However, while research on the relationships between the different aspects of intelligence has been quite prolific, empirical evidence regarding the functional and structural neural processes underlying these domains remains unclear.

Studying the neural correlates of EI is important for both theoretical and practical reasons. It helps understand the interaction between emotion and cognition, which in turn is of great importance for combating psychological and emotional disorders, and as a result, for creating optimal prerequisites for healthy functioning (Dolcos et al., 2011).

Emotional Intelligence

EI as a psychological construct emerged in the early 1990s to understand how emotions drive human behavior. Salovey and Mayer (1990) were the first to put forward this concept based on a subset of Thorndike's definition of social intelligence and Gardner's personal intelligence. Specifically, it refers to this knowledge about the self and others' internal states and behavior and learning to act upon them in a way that cultivates and amplifies inter-/intrapersonal relationships. Salovey and Mayer (1990) defined EI as "*the ability to monitor one's own and others' feelings and emotions, to discriminate among them and to use this information to guide one's thinking and actions*" (p. 189). They argued EI to be a set of skills and abilities involving mental processes such as 1) expressing and appraising emotions in the self and others; 2) regulating emotions; and 3) using emotions in adaptive ways. This model of EI is called the ability EI.

Another model of EI is Reuven Bar-On's trait model which describes an array of interrelated social and emotional competencies measured by self-assessments, such as the Bar-On Emotional Quotient Inventory (EQ-i; Bar-On, 2006) or other trait EI measures. A total score of EQ-i consists of five composite scale EQ scores for 1) intrapersonal relationships, 2) interpersonal relationships, 3) stress management, 4) adaptability, and 5) general mood (Bar-on, 2000). These scales are then further divided into fifteen subscale scores. Bar-On does not separate social intelligence and EI regarding shared skills and facilitators. They are instead combined to determine effective human behavior. The essence of emotional-social intelligence is considered to lay on the prior research conducted on alexithymia, the inability to describe, recognize and understand emotions. What distinguishes trait EI from ability EI is that the former measures behaviors in emotion-relevant situations whereas the latter is based more on the theoretical understanding of emotional functioning. More specifically, the ability EI measures are based on maximal performance on emotion-related problems, whereas the measures of trait EI are commonly based on self-reports.

During the development of these two models referred above, Goleman (1995) presented an additional model of EI, the mixed model. The mixed model takes advantage of both the competency (ability) and the general disposition (trait) of EI, and also the underlying personality characteristics not reflected in cognitive intelligence (Goleman, 2001). The mixed model was developed as a theory of performance to predict personal effectiveness at work and in leadership. According to Goleman (2001), EI consists of four competencies: 1) self-awareness; 2) social-awareness; 3) self-management; and 4) relationship-management. Whereas the first two competencies are based on emotion recognition, the latter two components reflect emotion regulation of the self and others. These can be assessed using the Emotional and Social Competence Inventory (ESCI; O'Connor et al., 2019). In 2002 a fifth competence, EI in leadership, was added to the model (Goleman et al., 2002).

Although different models of EI have emerged, the way EI is measured is nonetheless quite similar. All the measures produce a total EI score based on multiple facets/subscales. Furthermore, the facets within all three models have numerous conceptual overlaps. More specifically, most of the measures include aspects of emotion recognition and emotion regulation of the self and others, and strategically utilize the related emotions. The focus of this review will be on ability EI since it can arguably be assessed more objectively using performance-based measures, rather than self-assessments, thus simplifying the interpretation of the associated neural correlates.

The Theoretical Ability EI Framework

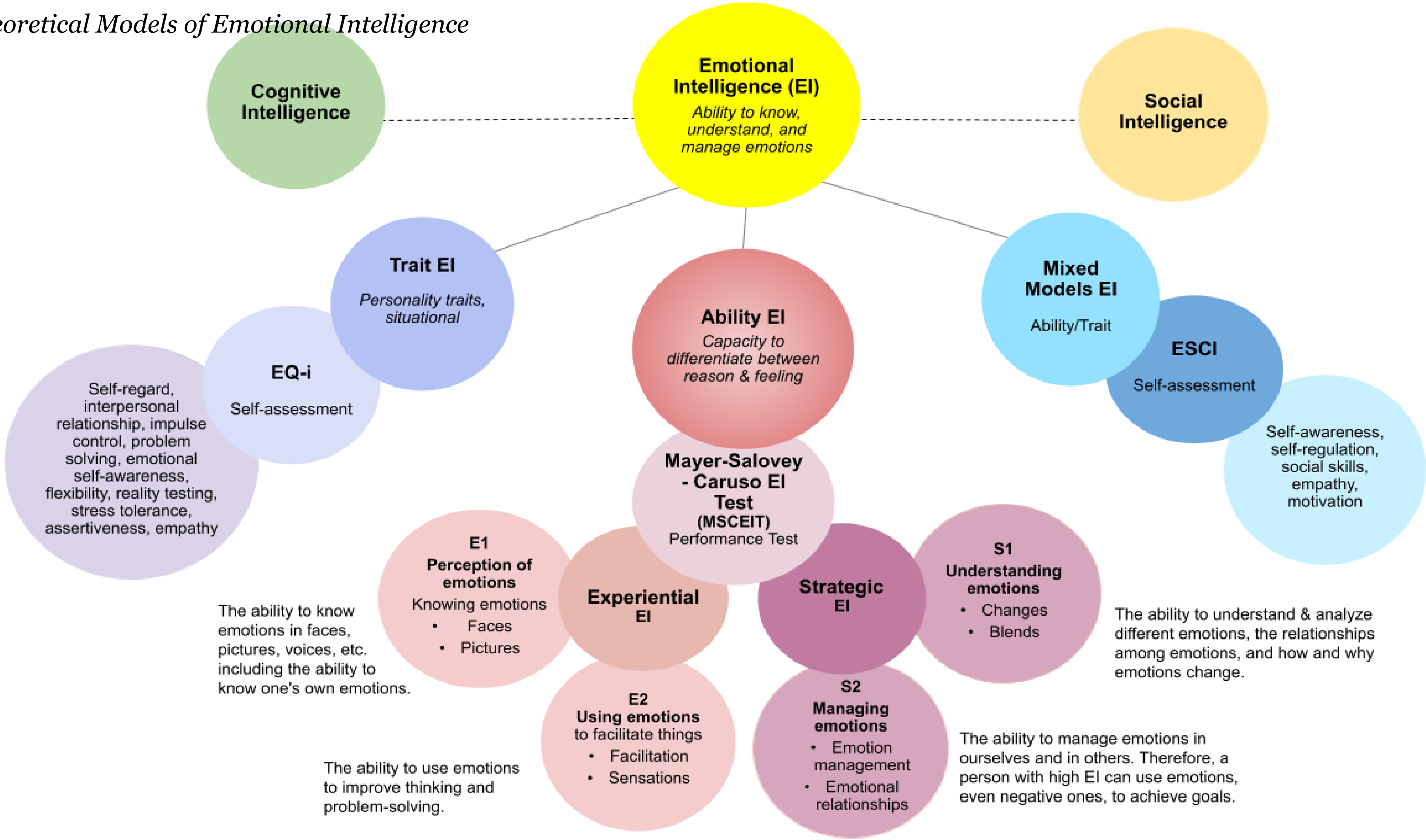
Ability EI is defined as the capacity to differentiate between reason and feeling (Mayer et al., 2016). The theoretical framework of ability EI consists of interrelated abilities of perceiving, using, understanding, and managing emotions, based on distinct psychological processes. To illustrate the relationships between these concepts, and also between the concepts related to EI in general as described above, we constructed Figure 1.

The two key facets of ability EI are experiential EI and strategic EI (Mayer et al., 2011). Experiential EI refers to emotion perception and information processing, whereas strategic EI refers to understanding and managing emotions. Ability EI can be assessed using an ability test such as the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT; Brackett & Salovey, 2006; Mayer et al., 2003; Mayer et al., 2016; Palmer et al., 2005). The MSCEIT uses 141 computer-administered items to rate various stimuli such as abstract pictures and faces on several emotional dimensions to see how emotions affect thinking. The two facets of ability EI can further be divided into four separately measured branches of MSCEIT (see APPENDIX A). The branch scores for perceiving emotions (E1) and facilitating emotions in thinking (E2) measure experiential EI, whereas the scores for understanding emotions (S1) and managing emotions (S2) measure strategic EI. Each of the branches is tested separately by different problem-solving tasks (see APPENDIX B; Brackett & Salovey, 2006; Mayer et al., 2003; Mayer et al., 2016). E1 is measured using faces and pictures, where participants are asked to link different emotions to viewed pictures. E2 is measured by asking participants to imagine and match emotions with other sensations (e.g., cold, red, sweet), and how moods enhance thinking. S1 is measured by tasks in which participants are asked how well they connect specific situations with certain emotions, and how the states of emotions change. Finally, S2 focuses on emotion management and emotional relationships, where participants are asked to analyze different actions and their effectiveness in regulating the emotions of oneself or of another person (Brackett & Salovey, 2006; Mayer et al., 2003; Palmer et al., 2005).

Some empirical studies suggest that there is a positive correlation between experiential EI and strategic EI, referring to ability EI as a holistic construct, whereas other studies underline

Figure 1

Theoretical Models of Emotional Intelligence



Note. Based on Bajaj & Killgore, 2021; Bar-On & Parker, 2000; Goleman, 1995; Mayer & Salovey, 1997.

their conceptual differences and relevance in different situations (Lim & Birney, 2021). Rossen et al. (2008) showed a correlation of 0.35 between the total scores of experiential EI and strategic EI, a positive, but low correlation in comparison to their respective correlations to the MSCEIT total score $r = 0.85$ and $r = 0.78$, respectively. The findings of Elfenbein and MacCann (2017) on interrelationships between the different facets of EI support the validity of EI as a type of intelligence. They did not however find the correlations between different branches of ability EI to be significantly larger within MSCEIT in comparison to other ability EI assessments, except for the correlation between self-regulation and other emotion regulation within S2, where the effect size was higher within MSCEIT 0.81 in comparison to non-MSCEIT assessments 0.59. Thus, although correlated it is unclear to what extent these constructs overlap.

Roberts et al. (2006) have questioned the validity of the E1 branch, while Joseph and Newman (2010) argued that the branch E2 is only a theoretical construct that does not have as strong an evidence base as the other three branches. Mayer et al. (2016) acknowledge this critique agreeing that sometimes other abilities than those suggested by the model may be used for problem-solving, such as understanding emotions instead of facilitating thoughts. However, they argue E2 to be a reasonable part of the model since the tasks involving this ability correlate with the overall scores of MSCEIT. Thus, Mayer et al. (2016) do not claim that the measured mental abilities always coincide with the abilities employed by an individual for solving a specific task.

The Relationship Between Ability EI and Psychopathology

Many psychiatric and neurological disorders, such as schizophrenia, autism, and Alzheimer’s disease, are associated with impairments in cognitive and emotional abilities (Operskalski et al., 2015). Research findings show that individuals with schizophrenia have an impaired ability EI (Frajo-Apor & Hofer, 2017). The MSCEIT branches found to be most impaired in schizophrenia are S1 and S2 (Martins et al., 2019). According to Wojtalik et al. (2013), patients in the early course of schizophrenia scored lower on the E2, S1, and S2 subscales, and showed a reduction in gray matter (GM) volume in the left parahippocampal gyrus. Further, the score on E2 and S2 branches for the patients with schizophrenia were associated with reduced right posterior cingulate GM volume. Also, the left superior parietal lobule has been linked to scores on S2 for participants diagnosed with schizophrenia as well as for healthy controls, with individual variation in network topology (Ling et al., 2019). For the individuals scoring lower on S2, the key brain network involved was the dorsal attention network, and for those scoring high on S2, the central network was the default mode network (DMN). Martins et al. (2019) reviewed thirty studies focusing on impairments in EI in schizophrenia patients. The results of the review suggest that schizophrenia patients have impairments in the S1 and S2 branches, and that they score lower in MSCEIT than healthy controls. However, most of the conducted research on the relationship between the ability EI and schizophrenia is cross-sectional.

A recent lesion-study (Jiang et al., in press) indicates that damage to the left ventrolateral prefrontal cortex (vlPFC) is associated with impaired abilities in managing emotions and correlates with increased risk for psychopathology. Results of a study comparing the relationship between the anterior DMN and EI in depressed patients and healthy controls suggest that depressed individuals have reduced connectivity between anteromedial PFC regions and brain areas included in emotion regulation in comparison to healthy controls (Sawaya et al., 2015).

In studies by Hooker et al. (2012, 2013) outpatients with schizophrenia participated either in a combined cognition and social cognition training or a placebo intervention. Cognition training consisted of tasks related to auditory and verbal information processing, whereas social cognition training focused on distinguishing emotions. Participants were randomly assigned either to take part in the training intervention or a placebo intervention (non-specific computer games). Participants were asked to perform emotion recognition tasks in which they had to identify basic emotional expressions while their brain activity was measured using functional magnetic resonance imaging (fMRI). Behavioral improvements were measured using MSCEIT subscale E1. Based on the findings of the study, the training intervention increased activity in the bilateral amygdala, right putamen, right medial PFC, and postcentral gyrus of the participants, to a greater extent than the placebo intervention. Also, the training interventions predicted a greater improvement in the ability to perceive emotions than the placebo intervention.

There are no or very few studies on the trainability of ability EI in non-clinical populations (Lim & Lau, 2021). A majority of the studies of EI in non-clinical settings are behavioral, often based on self-assessments using mixed models or trait EI measures.

Neural Correlates of Ability EI

Despite advances in neuroimaging techniques and the theoretical bases of ability EI, no precise neural correlates of ability EI have yet been well delineated (Smith et al., 2018). It is believed that EI relies on cognitive and emotional processing (Barbey et al., 2014). Brain imaging techniques such as structural magnetic resonance imaging (MRI) and fMRI have been used to study the anatomy and activity of the brain, respectively, whereas diffusion tensor imaging (DTI) has been used to detect white matter (WM) connectivity. The results of the studies within this area have however been inconsistent. Additionally, there is variety in the methods used to measure ability EI (Smith et al., 2018). Even event-related potentials (ERP) and electroencephalography (EEG) have been used as methods to measure related brain activity, but in this review, we will mainly focus on studies utilizing brain imaging techniques. Further, our focus will be on measuring ability EI with a performance-based measure, the MSCEIT. Trait-based studies of EI tend to be problematic since the validity of the self-evaluations concerning true abilities is difficult to assess.

Zysberg and Raz (2015) carried out a systematic review of the neurobiology of EI based on studies published over the past 15 years. They showed that, independently of the methodology and sample, all included studies indicated the central role of prefrontal cortices: orbitofrontal cortex (OFC), ventromedial prefrontal cortex (vmPFC), and dorsolateral PFC (dlPFC). It has been proposed that higher-order association areas vmPFC and dlPFC integrate subcortical limbic structures in influencing emotionally related behaviors (Krueger et al., 2009). Additionally, based on lesion-studies, the core brain areas included in various emotional abilities are vmPFC, amygdala, insula, and ACC (Hogeveen et al., 2016). Further, studies show that ability EI is positively correlated with the GM volume of vmPFC, insular cortex, social cognition network, and cognitive control network (Killgore et al., 2012). In the lesion-study by Krueger et al. (2009) it was shown that damage to vmPFC affects the branches of strategic EI negatively, whereas damage to dlPFC impairs abilities related to experiential EI. These results suggest that the central abilities of the MSCEIT branches would depend on distinct neural correlates.

However, the findings of Operskalski et al. (2015) indicate that, even if experiential EI and strategic EI can be defined as separable sub-facets, the neural processes underlying these facets overlap and include networks in the frontal, temporal, and parietal cortices. The results also show that the two branches E1 and S2 are based on common neural systems and share an interdependence in the social information network, the orbitofrontal, and the parietal cortex. Damage in these brain areas predicted impairments in both abilities, perceiving and managing emotions.

The Aim of This Systematic Review

The primary aim of this study was to examine the neural correlates of ability EI by conducting a systematic review. The focus of the review is on empirical studies investigating strategic and experiential EI. The primary research question was: Whether and to what extent experiential EI and strategic EI rely on similar or different neural substrates? To examine this, it was important to reflect on whether experiential and strategic EI truly are independent and dissociable constructs at the psychological level. Based on the previous literature, the hypothesis was that experiential EI and strategic EI rely partly on different, and partly on similar, neural substrates, due to the overlap of the psychological constructs and the co-dependence of the underlying psychological and physiological processes.

Some findings suggest that scores of the MSCEIT branches should be measured separately and not summarized as a single total score (Fiori & Antonakis, 2011). Therefore, understanding of whether experiential EI and strategic EI rely on similar or different neural substrates may offer a more detailed picture of how the different facets of ability EI relate to each other. This knowledge could also be used to enhance positive relationships and well-being through evidence-based interventions. It is suggested that higher EI leads to higher self-esteem and more positive mood states (Schutte et al., 2002).

Methods

Search Strategy

A systematic search was conducted by both authors independently on the 19th and 20th of February 2023, respectively. Both authors used a single search string (”emotional intelligence" OR "ability emotional intelligence" OR "experiential emotional intelligence" OR "strategic emotional intelligence" OR “ability EI” OR “experiential EI” OR “strategic EI” OR "Mayer-Salovey-Caruso" OR MSCEIT) AND (“neural correlates” OR fMRI OR MRI OR “Positron Emission Tomography” OR PET OR Neuroimaging OR "CT scan" OR "magnetic resonance imaging" OR "computed tomography" OR DTI OR “diffusion tensor imaging”). The same string was used in searches in the following three databases: Web of Science, Scopus, and MEDLINE EBSCO. No constraints on time range or language were set in the search phase. No additional studies were added from other sources.

The Inclusion and Exclusion Criteria

The inclusion criteria were (1) original articles published in peer-reviewed journals, (2) journals listed in Journal Citation Reports database, (3) empirical studies with at least one validated outcome measure, (4) written in the English language, (5) MSCEIT used to measure ability EI, (6) published from the year 2002 onward (MSCEIT created 2002), (7) human participants, (8) adults, and (9) neuroimaging studies (fMRI, MRI, PET, CT, DTI), (10) healthy participants, and (11) at least one MSCEIT subscale score for experiential EI or strategic EI reported.

The exclusion criteria for the review were (1) reviews, meta-analysis, or other publication types other than empirical studies, (2) articles written in other languages than English, (3) articles published before 2002, (4) animal studies, (5) studies on non-adults, (6) clinical or lesion studies, participants with psychopathology, (7) EEG or ERP used as methods, (8) other measures used to assess EI (e.g., trait EI), and (9) only the MSCEIT total score reported.

A total number of 440 articles were found through the database searches by both authors, (Web of Science, 105 articles; Scopus, 197 articles; Medline EBSCO, 138 articles). After removing

192 duplicates, 248 remaining articles were screened independently by the authors in the software Rayyan (Ouzzani et al., 2016) based on the titles and abstracts of the articles. Of these, 36 articles were excluded for being a wrong publication type (meta-analysis, reviews, conference papers, case reports, and book chapters). 184 articles were excluded due to an incorrect study design (not measuring EI or only behavioral studies), wrong outcome (not MSCEIT), or wrong population (animal or non-adult). The results of the independent screening for eligibility differed with seven articles. The authors discussed and compared these results, agreeing on including 20 articles in full-text screening.

Full-text articles of the remaining 20 articles were assessed for eligibility independently by the authors and then discussed. Of these, 15 articles were excluded. Six studies were excluded since they only used or reported a total MSCEIT score. Additional nine studies were excluded for the following reasons: seven for wrong population (psychopathology), one for wrong study design (sleep duration), and one being a lesion study and a pre-proofed article.

A total of five studies fulfilled the selection criteria described above and were included (see Figure 2 for a PRISMA flow chart for visualization of the systematic review process and details on inclusion and exclusion). All the included articles were published in journals included in Journal Citation Reports Database, with journal impact factors between 1,7 and 7,4.

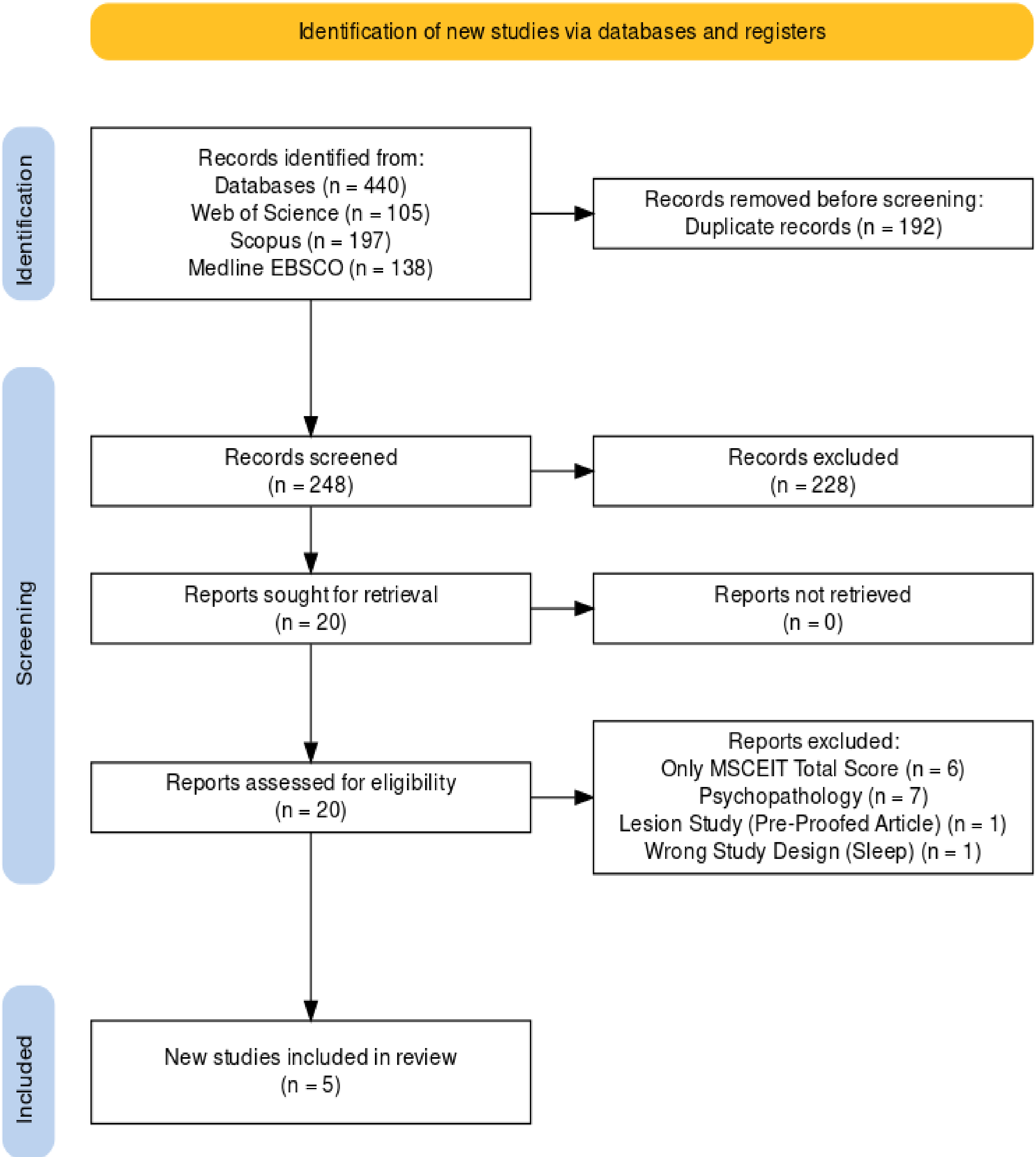
Collection and Extraction of Data

The validated outcome measures for this systematic review included comparing MSCEIT outcome scores for experiential and strategic EI to outcome measures of the respective brain imaging technique (GM volume, and structural, functional, and effective connectivities).

The data extracted from the articles included the following (1) authors and the year of publication, (2) demographic data of the sample (gender, mean age, health), (3) sample size, (4) study design, (5) methods, (6) outcome measures and (7) results related to ability EI.

Figure 2

PRISMA flow chart



Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis Campbell Systematic Reviews, 18, e1230. https://doi.org/10.1002/cl2.1230

Results

Study Characteristics

Descriptive information of the five included studies is listed in Table 1. A total of 141 English-speaking participants were included in the studies of which 48% were men. The mean age ranged from 29.25 years (*SD* = ± 7.30) to 30.56 years (*SD* = ± 8.39). Participants in all the five studies were from the same sample. In four of the studies (Killgore et al., 2012, 2013, 2017; Pisner et al., 2016), subsets of participants from the Boston metropolitan area were used, and in the fifth study participants from a larger region of New England were included. The hypotheses and research questions stated in all studies have been clearly defined with sufficient background information. Considering the outcome measures in all studies, it is clear that Killgore and colleagues have been utilizing the methods required in a sufficient manner. Additionally, the limitations of the studies are clearly stated and put into consideration further supporting the strengths of the studies. However, the restricted range of participants and the reuse of data samples within the studies will be further discussed.

All five studies used MSCEIT to measure ability EI. Two studies compared the ability and the trait model of EI, using both the MSCEIT and EQ-i, to find similarities and differences in GM volume (Killgore et al., 2012) or functional connectivity (Killgore et al., 2017). In one study (Killgore et al., 2013), following the completion of the EI tests, the participants underwent brain imaging while performing a dynamic facial trustworthiness task (DFTT). DFTT is a task where dynamically changing facial features affect trustworthiness judgment. The aim of the study was to see if there were any relationships between EI and activation in the somatic marker circuitry (SMC). According to the somatic marker hypothesis (SMH), there are three primary brain regions involved in judgment and decision-making in SMC, including amygdala, insula, and vmPFC (Damasio, 1994). The study conducted by Pisner et al. (2016) compared MSCEIT to the Wechsler Abbreviated Scale of Intelligence (WASI). This conventional intelligence scale was included as a covariate to determine the extent to which ability EI, specifically MSCEIT subscales, predict structural connectivity independently from cognitive intelligence. Lastly, the goal of the final

Table 1

Summary of the Included Studies

Study	Population	Mean Age (SD)	Measure	Comparison	Method	MSCEIT M (SD)	Outcome Measure	Main Results
Bajaj & Killgore, 2021	Healthy adults (n= 55) 26 men	30.6 (8.4)	MSCEIT	—	MRI rsfMRI	E1 = 105.76 (14.5) E2 = 105.33 (13.7) S1 = 101.51 (11.6) S2 = 96.62 (8.6)	Effective connectivity	**Experiential EI:** Right Anterior PFC → Left Anterior PFC **(-)** **Strategic EI:** Right Superior PC → Right Anterior PFC **(-)** **E2**: Left Anterior PFC → Right Anterior PFC **(+)**; Right Anterior PFC → Left Anterior PFC **(-)** **S1:** Left Insula → Dorsal ACC **(+)**; Right Insula → Right Anterior PFC **(-)** **S2:** Right Superior PC → Right Anterior PFC **(-)**
Killgore et al., 2012.	Healthy adults (n= 36) 20 men	30.0 (8.9)	MSCEIT	EQ-i	MRI	E1 = 104.58 (13.9)* E2 = 103.72 (15.8)* S1 = 100.19 (12.4)* S2 = 96.17 (8.8)*	Gray matter volume	**MSCEIT total score:** Left Posterior Insula **(+)** **Strategic EI:** Ventromedial PFC **(+)**; Left Posterior Insula **(+)**; Left Anterior Insula **(+)**; Ventrolateral PFC **(+)**
Killgore et al., 2013	Healthy adults (n= 39) 22 men	29.9 (8.6)	MSCEIT EQ-i	DFTT	MRI fMRI	E1 = 105.56(13.9) E2 = 104.44 (14.4) S1 = 100.69 (11.9) S2 = 97.18 (8.3)	Gray matter volume	**MSCEIT total score:** Ventromedial PFC **(+)** **Strategic EI:** Ventromedial PFC **(+)** **S1:** Ventromedial PFC **(+)** **Strategic EI:** Rostral ACC **(+)** **Experiential EI:** Rostral ACC **(+)**

Killgore et al., 2017	Healthy adults (n= 54) 26 men	30.1 (7.5)	MSCEIT	EQ-i	MRI rsfMRI	E1 =105.35(14.2)* E2 =104.22(14.4)* S1=100.52(12.0)* S2 = 97.18 (8.4)*	Functional connectivity	<u>Within - Network</u> **MSCEIT total score:** BGN **(-)** **E2**: BGN **(-)** **S2:** BGN **(-)** **MSCEIT total score:** P-DMN **(-)** **S2:** P-DMN **(-)** <u>Between - Network</u> **MSCEIT total score:** P-DMN / BGN **(-)** **S2:** P-DMN / BGN **(-)** **MSCEIT total score:** A-DMN / BGN **(-)** **E2:** A-DMN / BGN **(-)**
Pisner et al., 2016.	Healthy adults (n= 32) 16 men	29.3 (7.3)	MSCEIT	WASI	DTI	E1 = 105.91 (14.3) E2 = 104.66(13.0) S1 = 101.34 (11.5) S2 = 98.22 (7.9)	Structural connectivity	**S1:** Greater FA in left superior longitudinal fasciculus and dorsal corticospinal tract **(+)** **S2:** Greater FA in corpus callosum, right uncinate fasciculus and Genu **(+)**

Note. * Received the mean scores of MSCEIT subscales from William D. S. Killgore through personal communication; (+) Positively Correlated; (-) Negatively Correlated; MSCEIT, Mayer Salovey Caruso Emotional Intelligence Test; EQ-i, Bar-On Emotional Quotient Inventory; WASI, The Wechsler Abbreviated Scale of Intelligence; DFTT, Dynamic Facial Trustworthiness Task; EI, Emotional Intelligence; E1, perceiving emotions; E2, facilitating emotions; S1, understanding emotions; S2, managing emotions; FA, Fractional Anisotropy; BGN, Basal Ganglia/Limbic Network; A-DMN, Anterior Default Mode Network; P-DMN, Posterior Default Mode Network; MRI, structural Magnetic Resonance Imaging; rsfMRI, resting-state functional Magnetic Resonance Imaging; DTI, Diffusion Tensor Imaging; PFC, Prefrontal Cortex; ACC, Anterior Cingulate Cortex; PC, Parietal Cortex.

study was to compare effective connectivity findings associated with ability EI (Bajaj & Killgore, 2021). More specifically, to estimate the effective connectivity strength within the four resting-state networks (RSNs): 1) DMN, 2) dorsal attention network, 3) control-execution network, and 4) salience network.

The neuroimaging methods used in the studies were MRI, fMRI, resting-state functional magnetic resonance imaging (rsfMRI), and DTI. Killgore et al. (2012, 2013) collected MRI scans using a T1-weighted 3D MPRAGE sequence. T2-weighted fMRI scans were also collected in Killgore et al.'s (2013) study. All data went through statistical parametric mapping (SPM8) to perform voxel-based morphometric regression analysis. The number of voxels in significant clusters within the uncorrected height threshold ($p < 0.001$) was then returned and corresponded with the Montreal Neurological Institute (MNI) coordinates to confirm the location of the GM volume and its correlation with EI.

Pisner et al. (2016) studied the neural systems underlying ability EI by analyzing WM connectivity supported by DTI. Diffusion-weighted imaging data were analyzed using voxel-wise Tract-Based Spatial Statistics (TBSS) to generate the fractional anisotropy (FA), the most widely used metric for WM microstructural integrity. Each of the MSCEIT branches was separately used in regression analysis with FA ($p < 0.05$, FWE corrected) and registered into the MNI space to create maps of the FA tracts.

In the remaining two studies, all participants underwent MRI and rsfMRI scans, to investigate functional architecture of the brain at rest (Bajaj & Killgore, 2021; Killgore et al., 2017). The goal was to identify spatially distinct brain areas that display synchronous Blood Oxygenation Level Dependent (BOLD) fluctuations at rest, such as RSNs. Various methods exist for analyzing resting-state data. Independent component analysis was used in Killgore et al. (2017) study to find the temporal and spatial pattern of each RSNs from the data. Dual regression was then added to conduct within-network and between-network functional connectivity analysis to see the strength of correlation to trait and ability EI at a significance level of ($p<0.05$, FWE corrected). For effective connectivity analysis, Bajaj and Killgore (2021) used spectral dynamic causal modeling to draw inferences between ability EI and connectivity strength within the four aforementioned RSNs. Further, they used Spearman's partial correlation approach to determine the correlations at a significance level of (p_{FDR}<0.05).

GM Volume and Ability EI

Killgore et al. (2012) hypothesized that higher EI in both MSCEIT and EQ-i, especially aspects comprising emotional control, would be associated with greater GM volumes of the central SMC regions. The results of the study supported the hypothesis, suggesting a correlation between vmPFC and strategic EI, that is, the individuals' ability to understand and manage emotions. Also, the left posterior insula was associated with MSCEIT total score and strategic EI, and the left anterior insula and vlPFC with strategic EI. The biggest cluster size and GM volume were related to vmPFC suggesting its leading role in ability EI. However, no association was found between the amygdala and the ability EI. Furthermore, experiential EI was not found to be related to GM volumes of any of the above-mentioned brain areas of SMC.

Killgore et al. (2013) built upon the prior work on the relationship between EI and SMC. The hypothesis was that higher scores on EI would be associated with higher activation within the nodes of SMC, especially within the vmPFC. The results showed that decreasing trustworthiness (high trustworthy faces convert to neutral) was associated with strategic EI and the activation of vmPFC. Further, rostral anterior cingulate cortex (rACC) was correlated with both experiential and strategic EI. Within hypothesized brain regions the results showed no correlation to EQ-i. As in the previous study, no correlation was found between the amygdala and ability EI.

Brain Connectivity and Ability EI

Pisner et al. (2016) expected the MSCEIT branches E1 (perceiving emotion) and S1 (understanding emotions) to be related to greater FA within inferior fronto-occipito fasciculus, and inferior and superior longitudinal fasciculus, predicting the strength of structural connectivity. They further hypothesized that the branches E2 (facilitating emotions) and S2 (managing emotions) would be associated with higher connectivity in the uncinate fasciculus, anterior cingulum, and anterior forceps. This proved to be true for S1, which was found to correlate with greater FA in the left superior longitudinal fasciculus and dorsal corticospinal tracts. S2 correlated with increased FA mostly in tracts of the corpus callosum, right uncinate fasciculus, and genu. However, neither E1 nor E2 were found to correlate with WM integrity.

According to Killgore et al. (2017), a negative relationship exists between task-positive networks and RSNs. For this reason, the authors hypothesized that EI would also be anti-correlated with functional connectivity within and between DMN and networks involved in emotional processing during the resting-state. The results of the study showed that MSCEIT total score was correlated with brain activity in both the basal ganglia/limbic network (BGN) and the DMN, and thus that the connectivity within and between these networks can be associated with ability EI. MSCEIT total score, driven primarily by E2 and S2, was found to have an anti-correlation with connectivity within BGN. This was also true for the connectivity of posterior DMN, driven primarily by S2. Both anterior and posterior DMN were significantly correlated with BGN, with a partial correlation coefficient of $r = 0.93$ and $r = -0.75$, respectively. MSCEIT total score and E1 were negatively correlated with the connectivity between anterior DMN and BGN ($p=0.05$) and ($p=0.004$) respectively. Further, MSCEIT total score and S2 were positively correlated with connectivity between posterior DMN and BGN ($p=0.03$). Again, no significant effects associated with EQ-i for any of the networks of interest were found.

Bajaj & Killgore (2021) hypothesized that there would be an association between the ability EI scores and the strength of effective connectivity within the brain regions related to emotion processing, such as the insula and areas of PFC. Significant correlations were found between ability EI measures and the strength of connectivity within the central executive network and salience network, whereas no such correlations were found within DMN and dorsal attention network. Within the central executive network, a negative correlation was found, from the right anterior PFC to the left anterior PFC, with E2 ($p_{FDR}=0.002$) and experiential EI ($p_{FDR}=0.012$), and a positive correlation from the left anterior PFC to the right anterior PFC with E2 ($p_{FDR}=0.027$). Further, the connectivity strength from the right superior PC to the right anterior PFC was negatively correlated with S2 ($p_{FDR}=0.002$) and strategic EI ($p_{FDR}=0.005$). Within the salience network, in turn, a negative correlation from the right insula to the right anterior PFC was found with S1 (p_{FDR}=0.041), and a positive correlation from the left insula to dorsal ACC and S1 (p_{FDR}=0.041).

Discussion

This systematic review aimed to examine the neural correlates of ability EI with a focus on empirical studies on experiential and strategic EI. The research question we strived to answer was whether, and to what extent, experiential and strategic EI rely on similar or different neural substrates. The correlations found in the included studies in this review point to prefrontal, insular, and cingulate cortices as primary brain regions involved in ability EI. Three of the included studies (Bajaj & Killgore, 2021; Killgore et al., 2013; 2017) showed that experiential and strategic EI rely on partly different, and partly shared, neural processes. The results of the two remaining studies were only related to strategic EI (Killgore et al., 2012; Pisner et al., 2016).

Neural Correlates of Experiential EI

The results from the included studies show that experiential EI and E2 have been associated with effective and functional connectivity in the anterior regions of PFC and DMN/BGN, respectively. This will be discussed further down since they share similar correlates with strategic EI. However, no association with E1 was found in the reviewed studies.

The dlPFC is said to play a central role in modulating abilities needed in working memory and visual motor representations related to goal-directed behavior (Barbey et al., 2013). According to Krueger et al. (2009), damage in dlPFC affects experiential EI abilities negatively, suggesting that dlPFC is a central region for perceiving emotions and facilitating thought capacities. However, no support for the association between dlPFC and experiential EI was found in the reviewed studies.

No correlations were found between experiential EI and the structural connectivity in sensory-affective tracts by Pisner et al. (2016). Therefore, researchers questioned the validity of experiential EI branches. They suggest that the weaker correlations of E1 and E2 to measured brain areas could depend on the incompleteness or unreliability of the psychological constructs or the methodologies used for measuring experiential EI. They propose that developing EI psychometrics is needed in future research.

Neural Correlates of Strategic EI

Results of Killgore et al.'s (2012, 2013) studies on GM volume support Krueger et al.'s (2009) earlier findings on combat veterans emphasizing the central role of vmPFC in strategic EI. The vmPFC is suggested to modulate emotional responses within the limbic system (Johnstone et al., 2007), playing a role in decision-making, emotion regulation, social cognition, and self-relevance (Bechara et al., 2000; Hiser & Koenigs, 2018; Roy et al., 2012). A systematic review by Zysberg and Raz (2015), and a lesion study by Hogeveen et al. (2016) also highlighted the vmPFC as a central region in ability EI along with the insula, ACC, and amygdala. These regions are suggested to play a role in self-monitoring and emotional processing in an interplay (Beer et al., 2006). Damage to vlPFC has been associated with impairments in emotion regulation (Jiang et al., in press). Strategic EI was found to be positively correlated with vlPFC GM volume (Killgore et al., 2012).

GM volumes of the left anterior and posterior insula were found to be positively correlated with strategic EI total score (Killgore et al., 2012). These regions have been associated with interoception and self-awareness (Straube & Miltner, 2011). Insula is considered to hold a key role in processing interoceptive emotional cues, related to perceiving and understanding one's own bodily sensations and emotions (Alkozei & Killgore, 2015). However, no association with perceiving emotions was found in the reviewed studies.

The large bundle of association fibers in the superior longitudinal fasciculus, corpus callosum, and uncinate fasciculus structural connectivity was correlated with strategic EI (Pisner et al., 2016). The corticospinal tract, which consists of fibers in motor cortices, was associated with strategic EI within the same WM integrity. The corticospinal tract has been shown to generate somatic feedback that mediates motor responses as part of approach and avoidance behaviors (Coelho et al., 2010). In the context of EI, perhaps greater FA in these tracts relates to one's ability to use these somatic feedbacks to empathize with others (Pisner et al., 2016). This highlights the SMH even further.

Neural Correlates Common to Experiential and Strategic EI

According to the results of the DFTT study (Killgore et al., 2013), both experiential and strategic EI were positively correlated with the activation of rACC independently, suggesting that rACC plays a role in monitoring affective conflicts and regulating emotional responses (Etkin et al., 2011).

Reduction in GM density in the left parahippocampal gyrus and right posterior cingulate cortex has been associated with lower scores on E2, S1, and S2 (Wojtalik et al., 2013). Yet, Hooker et al.'s (2012, 2013) findings with schizophrenia patients suggest that social training in emotion perception could improve E1. Even these results imply an interconnection between the underlying neurocircuitry associated with the two facets of ability EI. The reviewed studies did not reveal related results.

An anti-correlation was observed between the ability EI total score and functional connectivity within BGN, driven by both E2 and S2 (Killgore et al., 2017), suggesting that there is an interplay between these abilities. In other words, perhaps managing and facilitating emotions have common neural correlates and when the connectivity within BGN is downregulated, the ability to perform ideally in these branches is enhanced. Furthermore, an anti-correlation was also found within the posterior DMN, primarily driven by S2. When it comes to between networks, the ability EI total score, driven by S2 and E1, was found negatively correlated with posterior DMN and BGN and was positively correlated with anterior DMN and BGN, respectively. BGN has been associated with emotion processing and reward tasks (Laird et al., 2011), and anterior DMN with autobiographical memory (Andrews-Hanna et al., 2011). These results suggest that individuals with low ability EI total score, and the respective dominant branch scores, have a stronger positive connection between BGN and DMN, and may face challenges in regulating emotional sensations and experiences via PFC (Killgore, 2017). Furthermore, research has shown (Ling et al., 2019; Sawaya et al., 2015) that both depressed patients and individuals with schizophrenia have a molecular pathophysiology that disrupts the anterior DMN connectivity to emotional regulatory regions, resulting in poor emotional facilitation and social functioning.

According to Bajaj & Killgore (2021), higher experiential and strategic EI are associated with effective connectivity from the left to the right anterior part of the PFC. The dominant negative effective connectivity within the right hemisphere and between the right to left hemispheres could imply that greater right hemisphere involvement results in lower levels of ability EI. In a review by Gainotti (2019), the right hemisphere dominance was found to be linked to greater negative emotional comprehension and expression. This further supports the association between negative right hemisphere dominance and the lower ability EI, since downregulating negative emotional reactions is in general considered to be challenging.

Operskalski et al. (2015) suggested that the two facets of ability EI, even if separable, are interrelated, depending on brain networks within the frontal, temporal, and parietal cortex. The findings of this systematic review are in line with Operskalski et al.'s (2015) suggestion that the two facets of ability EI depend partly on different neural correlates, but also on highly intertwined and complex neural networks.

Limitations and Future Research

Several limitations should be considered when interpreting the results of the included studies. Firstly, the number of articles included in the study is very limited which makes it difficult to draw any solid conclusions. The strict inclusion criteria were based on our primary research interest in comparing the neural substrates of experiential and strategic EI in healthy adults. An alternative to broaden the scope could have been to include clinical studies in the review.

Also, the limited number of authors behind the relevant studies reveals that the field of study is still in its infancy, narrowing the perspective and lowering the perceived objectivity. Notable to the included studies is that Killgore, a leading researcher in the field, was a co-author in all the included five studies. Moreover, the participants in the studies were from the same database, therefore lacking heterogeneity in background characteristics such as age, language, and cultural and educational backgrounds. Although the gender distribution of the participants was relatively even, the fact that the possible impact of gender was not discussed in the studies could be seen as a limitation. Joseph & Newman (2010) suggest that tests measuring EI might work in favor of women. Yet, another limitation is the small sample sizes in the included studies, sharing the same participants, reducing the statistical power of the results. Therefore, replications are needed with larger samples and participants with more heterogeneous backgrounds, also covering psychopathology and neuropathology.

Comparing the findings of the studies is challenging due to the different methodological approaches and their respective outcome measures, and the complexity of the underlying processes. The results should be interpreted with caution because of the correlational nature of the studies. No causal relationships can be drawn. Even in the case of effective connectivity regarding directionality, the reliability of the large-scale measures is still underdeveloped (Bajaj & Killgore, 2021). Recommendations for future research include combining rsfMRI with task-based brain-imaging studies, replications using high-resolution fMRI, and further developing EI-related psychometrics.

Based on the findings of this review, the question of the validity of MSCEIT, especially experiential EI, and the accuracy of the underlying psychological constructs, is relevant to discuss. Roberts et al. (2006) challenged the construct validity of E1. Based on the results of their study comparing the subscores of MSCEIT to established measures used in emotion research in related psychological processes, the analysis gave support to distinct psychological constructs of experiential and strategic EI, but less so for the distinction of the four branches. Construct validity of especially E1 was low, however, the methodological differences between MSCEIT and the emotion research measures might weaken the validity of the carried-out comparison (Roberts et al., 2006).

Fiori et al. (2014) suggest MSCEIT is best suitable to measure individuals with low EI, questioning the validity of MSCEIT as a measure for differentiating between individuals scoring from average to high in EI. Maul (2012) argues that there is scarce evidence on the causal relationship between recognized variation in test performance and the validity of MSCEIT scores, whereas Gutierrez-Cobo et al.'s (2016) study suggests that performance-based ability EI, is related to efficiency in emotionally laden cognitive tasks. Mayer et al. (2016) agree that the problem areas should be clearly described, the content of the test chosen should match the problem definition, and only valid tests with well-defined subject matters should be used.

Also, The surprising result that the amygdala was not correlated with any of the EI measures could depend on the amygdala's nonlinear responsiveness to facial trustworthiness, limited measurement power to detect such relationships, or the experimental study design (Killgore et al., 2013).

Ethical and Societal Aspects

All the included studies in this review were approved by ethical review boards, and all participants gave written informed consent prior to participating in screening interviews for clinical diagnosis or other health issues. Participants took part voluntarily and received nominal compensation for their participation. The neuroimaging methods used were non-invasive.

Conclusion

This systematic review aimed to investigate the current state of knowledge on the neural correlates of ability EI. Our focus was on the differences and commonalities in the neural underpinnings of its two facets, experiential and strategic EI, in healthy adults. Based on the reviewed studies, the main brain regions related to ability EI as a whole were prefrontal, insular and cingulate cortices. Neural correlates associated primarily with strategic EI were GM volumes of the left vmPFC, vlPFC, and the left posterior and anterior insula. Both strategic and experiential EI were found to be correlated with rACC GM activation. In addition, both facets showed association with the effective connectivity of the anterior PFC and an anti-correlation in functional connectivity within and between BGN and DMN. In summary, the findings of the review suggest that experiential and strategic EI rely partly on distinct, and partly on common, neural circuitry. However, the field of EI research is still in its infancy. Therefore, more studies, as well as further development of EI measurement methodology, are needed. Increased knowledge about the neural basis of EI will enable a deeper understanding of human interaction and psychological well-being, and hopefully give us more tools to support well-being and flourishing in the future.

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Appendix

Appendix A

*The Four-branch Model of Emotional Intelligence**

	Emotional Intelligence
Branch name	**Brief description of skills involved**
Perception of emotion (Branch 1)	The ability to perceive emotions in oneself and others, as well as in objects, art, stories, music, and other stimuli.
Use of emotion to facilitate thinking (Branch 2)	The ability to generate, use, and feel emotions as necessary to communicate feelings, or employ them in other cognitive processes.
Understanding of emotion (Branch 3)	The ability to understand emotional information, how emotions combine and progress through relationships and to appreciate such emotional meanings.
Management of emotion (Branch 4)	The ability to be open to feelings, to modulate them in oneself and others so as to promote personal understanding and growth.

*Note. Brack*ett & Salovey, 2006, p. 35. Perception of emotion (Branch 1) corresponds to E1 in this systematic review; Use of emotion to facilitate thinking (Branch 2: E2); Understanding of emotion (Branch 3: S1); Management of emotion (Branch 4: S2); * More specifically Ability Emotional Intelligence.

Appendix B

The Four-branches of Emotional Intelligence Measured by the MSCEIT*

Branch 1: **(Perception of emotion)**	**Branch 2:** **(Use of emotion to facilitate thinking)**	**Branch 3:** **(Understanding of emotion)**	**Branch 4:** **(Management of emotion)**
Task 1: Faces Participants view photographs of faces and identify the emotions in them.	*Task 3: Sensation* *Which tactile, taste, and color sensations are reminiscent of a specific emotion?*	*Task 5: Blends* Which emotions might blend together to form a more complex feeling?	*Task 7: Emotion management* How effective alternative actions would be in achieving a certain outcome, in emotion-laden situations where individuals must regulate their feelings
Task 2: Pictures Participants view photographs of faces and artistic representations and identify the emotions in them.	*Task 4: Facilitation* How moods enhance thinking, reasoning, and other cognitive processes	*Task 6: Changes* How emotions progress and change from one state to another	*Task 8: Relationship management* Test-takers evaluate how effective different actions would be in achieving an emotion-laden outcome involving other people

Note. *Brack*ett & Salovey, 2006, p. 37. Branch 1 (Perception of emotion) corresponds to E1 in this systematic review; Branch 2 (Use of emotion to facilitate thinking: E2); Branch 3 (Understanding of emotion: S1); Branch 4 (Management of emotion: S2); * More specifically Ability Emotional Intelligence.