Abstract

People with agenesis of the corpus callosum (AgCC) with normal general intelligence have deficits in complex cognitive processing, as well as in social cognition. It is uncertain the extent to which impoverished processing of emotions may contribute to social processing deficiencies. We used the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT) to clarify the nature of emotional intelligence (EI) in 16 adults with AgCC. As hypothesized, persons with AgCC exhibited greater disparities from norms on tests involving more socially complex aspects of emotions. The AgCC group did not differ from norms on the Experiential subscale, but they were significantly below norms on the Strategic subscale. These findings suggest that the corpus callosum is not essential for experiencing and thinking about basic emotions in a 'normal' way, but is necessary for more complex processes involving emotions in the context of social interactions.

Key Words: Corpus callosum, emotional intelligence, social cognition

Emotional Intelligence in Agenesis of the Corpus Callosum

Introduction

The role of interhemispheric connectivity in neurocognitive disorders, and particularly disorders of social cognition, is still largely unknown. Agenesis of the corpus callosum (AgCC) is a congenital brain disorder in which the bundle of approximately 200 million axons comprising the corpus callosum fails to develop (Tomasch, 1954). Although initially thought to be rare, increased utilization of more sophisticated brain imaging techniques has demonstrated that AgCC occurs in approximately 1 in 4,000 births, making it one of the more commonly occurring congenital brain disorders (Glass, Shaw, Ma, & Sherr, 2008; Guillem, Fabre, Cans, Robert-Gnansia, & Jouk, 2003; Wang, Huang, & Yeh, 2004). Callosal absence in AgCC may be complete or partial. While a body of research is accumulating regarding the cognitive outcome of AgCC, including a small body of work on social cognition, as yet limited research has been done to assess characteristic patterns of emotional functioning in these individuals. This study used the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT) to describe patterns of strengths and weaknesses in emotional processing in individuals with AgCC.

Cognitive and Social Functioning in AgCC

Although many persons born with AgCC also have other comorbid neurological disorders and/or intellectual disability, a significant portion of this group have an IQ that falls within the normal range (i.e., FSIQ > 80) and have no other major neurological abnormalities other than complete or partial absence of the corpus callosum (Bogen, 1985; Chiarello, 1980; Paul et al., 2007; Sauerwein, Nolin, & Lassonde, 1994). Neuropsychological research in this subgroup (sometimes referred to as Primary AgCC or Isolated AgCC) allows for the unique opportunity to better understand the cognitive functions mediated by the corpus callosum.

In AgCC, interhemispheric interactions are limited to other cerebral commissures, particularly the anterior commissure that is typically present despite callosal absence. However, transfer of information between the right and left hemispheres via the anterior commissure appears to be largely limited to more readily encoded information – e.g. letters versus complex patterns of dots, or basic color information (Brown, Bjerke, & Galbraith, 1998; Brown, Jeeves, Dietrich, & Burnison, 1999; Brown, Thrasher, & Paul, 2001; Fisher, Ryan, & Dobyns, 1992). Consistent with this limitation in interhemispheric interactions, a growing body of research suggests that observed cognitive impairments are more pronounced in AgCC as task complexity increases, particularly if the task demands rapid, novel problem-solving (Brown, Anderson, Symington, & Paul, 2012; Brown & Paul, 2000; Gott & Saul, 1978; Marco et al., 2012; Sauerwein & Lassonde, 1994; Smith & Rourke, 1995; Solursh, Margulies, Ashem, & Stasiak, 1965). In particular, social functioning (i.e., adequately understanding and responding within social interactions) involves multiple complex cognitive processes and requires a high degree of interhemispheric processing. In fact, reports from family members of persons with AgCC have suggested that this is one of the most noticeable and challenging developmental areas for people with AgCC (Badaruddin et al., 2007; Brown & Paul, 2000).

Past research has elucidated some of the specific underlying factors that are contributory to social dysfunction in AgCC, including deficits in basic semantic language processing (Brown & Paul, 2000; Dennis, 1981; Jeeves & Temple, 1987; Temple, Jeeves, & Vilarroya, 1990), comprehension of nonliteral and second-order meanings in language (Brown, Paul, Symington, & Dietrich, 2005; Brown, Symington, Van Lancker-Sidtis, Dietrich, & Paul, 2005; Symington, Paul, Symington, Ono, & Brown, 2010), theory of mind (Symington et al., 2010; Temple & Vilarroya, 1990), narrative generation (Paul, Schieffer, & Brown, 2004; Turk, Paul, Symington,

& Brown, 2009), and social behavior (Badaruddin et al., 2007; Brown & Paul, 2000). Symington et al. (2010) found that participants with AgCC exhibited significant deficits in social understanding and comprehension when viewing video-taped vignettes of interpersonal interactions. These deficits were not evident on two other paper-and-pencil tests of social understanding examined in this study (the Happe Theory of Mind Stories and the Adult Faux Pas Test), suggesting social deficits become most evident when test stimuli involve real-time processing of social scenarios, multi-sensory perception, and cognitive integration.

In addition to specific deficits in comprehension of social situations described above, recent reports indicate elevated rates of autism spectrum disorder (ASD) in the AgCC population. In adults with AgCC, estimated rates of an autistic spectrum behavior profile range from 18% (Lau et al., 2013) to ~30% (Paul et al., 2014). In children with AgCC, 45% exceeded the autism-screening cut-off score of 76 on the child versison of the Autism Quotient (Lau et al., 2013). Badaruddin et al. (2007) found that only older children ages 6-11 were rated by family members as showing a significant rate of problems in social, emotional, and behavioral functioning at both the borderline and clinically significant levels. An age and IQ matched group of individuals with ASD were also impaired in these areas, but the group with AgCC were significantly less impaired than individuals with ASD.

Emotional Functioning in AgCC

Given the critical role of understanding one's own emotions and the emotions of others to responding appropriately in social contexts, it is important to determine whether persons with AgCC have deficits in emotional functioning, and, if so, what is the specific nature of these deficits. A few studies using a variety of measures developed for other purposes suggest that persons with AgCC have problems regulating emotion (Badaruddin et al., 2007), recognizing

their emotional state (Paul et al., 2006), verbally expressing emotion (Turk et al., 2009; Brown & Paul, 2000; O'Brien, 1994), and verbally identifying emotions expressed by others (Symington et al., 2010).

Bridgman et al. (2014) found that individuals with callosal agenesis were impaired at recognizing emotions in faces, with lower accuracy particularly in judging fear and anger. These impairments were directly associated with atypical patterns of facial scanning involving diminished attention to the eye region. Similarly, individuals with AgCC provided unusual ratings of emotional intensity and valence (i.e. location on a range from positive to negative) for a series of pictures with well-established affective content (Paul et al., 2006). Valence ratings given by individuals with AgCC were highly variable and were insensitive to the picture's pre-determined emotion categorization (based on published normative dataset). Likewise, their arousal ratings of these images were generally lower than the control group. Despite their insensitive ratings of arousal and valence (especially for negative images), participants with AgCC showed large autonomic responses while viewing the images that were consistent with the arousal content of the pictures and discriminated between emotions. This indicates that despite intact ability to respond psychophysiologically to emotional images, individuals with AgCC apparently do not utilize these responses in the judgment of the emotional content of images.

Turk et al. (2009) studied emotional content in the semantics of stories provided by individuals with AgCC. Persons with AgCC used fewer emotion words than matched controls in their narrations based on the pictures of the Thematic Apperception Test (TAT). They particularly used fewer words pertaining to negative emotions, despite the fact that the TAT pictures are designed to elicit such emotions. In addition, when they did use emotion words,

participants with AgCC tended to use emotional language that was inappropriate to the narrative context that they provided.

The current study directly examines the performance of adults with AgCC on various aspects of emotion processing, ranging from the basic capacities to experience and perceive emotions to more complex cognitive processing of multiple emotions and emotions within a social context. These various capacities for processing and responding to emotions are often summarized in the general concept of emotional intelligence.

Emotional Intelligence

Over the last few decades, there has been increasing interest in the concept of emotional intelligence (EI) as a distinct cognitive ability. Mayer and Salovey (1997) theorized that EI was comprised of four main factors, namely: emotional perception and expression, using emotions to facilitate adaptive thinking, understanding and analyzing emotions, and regulating emotions. These four factors, or "branches", were conceptualized as hierarchical and developmental. Emotional perception is developed earliest in life and represents the most basic and implicit aspect of EI, whereas at the other end of the continuum emotional regulation does not emerge until later and involves a much more sophisticated and conscious integration of psychological, emotional and cognitive processes. The Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT; Mayer, Salovey, & Caruso, 2002) was constructed to assess these levels of emotional functioning, with the overall score conceived of as a global measure of EI.

The MSCEIT has several advantages over other EI measurements. First, while some EI researchers have criticized this construct as being too broad and unclearly defined (see Roberts, Schulze, Zeidner, & Matthews, 2005), the MSCEIT was developed based on the well-defined four-branch model of EI. Thus, EI on the MSCEIT is actually measureable as four distinct

constructs. Second, unlike other measures of EI, the MSCEIT is the only comprehensive ability-based EI measure. While other valid EI measures exist, such as the Bar-on Emotional Quotient Inventory (EQ-i; Bar-on, 1997), these instruments rely on self and informant questionnaires, and as such do not objectively measure performance. Additionally, as an ability-based EI measure, the MSCEIT has better divergent validity from other factors, such as personality traits and subjective well-being, when compared to well-established self-report EI measures (Brackett & Mayer, 2003; Conte, 2005).

The importance of EI as a construct lies in its relationship to important aspects of people's lives, such as relationship satisfaction, academic achievement, and occupational success. For example, higher EI scores (as measured by the MSCEIT) are significantly associated with less cognitive effort on problem-solving tasks (Jausovec, Jausovec, & Gerlic, 2001), better stress management and coping (Matthews et al., 2006; Gohm, Corser, & Dalsky, 2005; MacCann, Fogarty, Zeider, & Roberts, 2011), better job performance (Brackett, Rivers, & Salovey, 2011; Day & Carroll, 2004; Lopes, Grewal, Kadis, Gall, & Salovey, 2006), better academic performance (Barchard, 2003; Brackett et al., 2011; Gil-Olarte Marquez, Palomera Martin, & Brackett, 2006; Mestre, Guil, Lopes, Salovey, & Gil-Olarte Marquez, 2006, MacCann et al., 2011), and better social functioning (Aguirre, Sergi, & Levy, 2008; Brackett et al., 2011; Brackett, Rivers, Shiffman, Lerner, & Salovey, 2006; Brackett, Warner, & Bosco, 2005; Day & Carroll, 2004; Gil-Olarte et al., 2006; Lopes et al., 2004; Lopes, Salovey, Cotes, & Beers, 2005; Lopes, Salovey, & Straus, 2003; Mestre et al., 2006; Mueller & Curhan, 2006). In addition, MSCEIT EI scores are negatively associated with more illicit drug use, adolescent tobacco and alcohol use, risky behaviors, and interpersonal aggression (Brackett & Mayer, 2003; Brackett, Mayer, & Warner, 2004; Rivers et al., 2013; Trinidad & Johnson, 2002), as well as various forms

of psychopathology (Eack et al. 2010; Gardner & Qualter, 2009; Hertel, Schutz, & Lammers, 2009; Kee et al., 2009). Overall, these behavioral outcomes are most consistently associated with performance on the branches that make up the Strategic EI domain (i.e., Emotional Understanding and Emotional Management; e.g., see Matthews, Zeidner, & Roberts, 2012).

Strategic EI also appears to be important in the more subtle and qualitative aspects of social interactions (Matthews et al., 2012). Specifically, when examined at the branch level, only Emotional Management scores were positively associated with higher quality self and peer-rated social interactions in American college students, and this relationship remained after controlling for Big Five personality traits (Lopes et al., 2004; Lopes et al., 2003). Lopes et al. (2004) also found that Emotional Management was the only branch related to perceived quality of social interactions with the opposite sex in German college students, again after controlling for personality characteristics. Finally, in a group of 127 Spanish adolescents, only the Understanding and Managing Emotions branches were related to better peer and teacher rated social outcomes after controlling for verbal intelligence and personality traits (Mestre et al., 2006). These findings suggest that Strategic EI, and managing emotions in particular, appear to be relevant the qualities of social interactions.

While EI has not been investigated in AgCC, there is some EI research in populations with similar neurodevelopmental social and emotional dysfunction, such as persons with ASD. Montgomery et al. (2010) found that although participants with ASD reported having significantly greater interpersonal problems and social and emotional difficulties, they actually performed significantly better than the norm on the MSCEIT branches assessing Perceiving, Using, and Understanding Emotion. The authors attributed the discrepant results to the elevated verbal IQ (M = 114) in the participants with ASD. The authors pointed out that this failure to

find deficits in EI (i.e., the MSCEIT) in the ASD group was similar to findings related to theory of mind, wherein participants with ASD often perform normally on these measures when there are no time constraints despite having real-life impairments in theory of mind. Montgomery et al. concluded that, despite deficits in the processing required to navigate socioemotional situations in the real world, the ASD group in their study was able to utilize their high cognitive and verbal reasoning abilities to solve the emotional problem-solving tasks on the MSCEIT. Despite issues related to IQ in this research, there was nevertheless a pattern reflecting lower scores on Managing Emotions than on the other three branches. The behavioral similarities between ASD and AgCC suggest that this pattern may also exist in AgCC.

Rationale and Hypotheses

Although several research studies have suggested that identification and labelling of emotions are deficient in persons with AgCC, more research is necessary to determine the extent to which these weaknesses are specific to the basic experience and recognition of emotion, or extend to the cognitive and strategic use of information regarding emotions in social contexts. Based on the research to date suggesting that individuals with AgCC have deficiences in other domains of cognitive and social functioning, it was hypothesized that (1) they would have significantly low EI scores compared to the normative MSCEIT sample. Given the general cognitive profile of AgCC involving difficulties in complex, novel problem solving, and given the role of Strategic EI in the qualitative domains of social functioning that persons with AgCC find difficult, it was also hypothesized that (2) their scores would be particularly low in the area of Strategic EI compared to Experiential EI.

Method

Participants

Participants in this study were 16 adults (age 18-57, M = 35.31±12.05, 9 male, 7 female) with complete (12) or partial (4) AgCC. This group included only those individuals with AgCC that was most clearly not complicated by other brain abnormalities in order to focus on the outcome of AgCC itself. All participants had full-scale intelligence quotient (FSIQ) within the normal range (83-129, M = 98.69±14.76) based on Wechsler intelligence tests. (Because IQ testing was conducted as part of our ongoing research program, it was not always administered at the same time as the MSCEIT. 14 participants were tested with the Wechsler Adult Intelligence Scale – III (WAIS-III) and 2 participants were tested at an earlier time with the Wechsler Intelligence Scale for Children – IV (WISC-IV). Index scores for the two participants tested with the WISC-IV did not differ from the WAIS-III index scores for the 14 additional participants, so index scores were combined for the following descriptive analyses. On average, the AgCC group did not differ from a mean of 100 for FSIQ, Verbal Comprehension Index (VCI; 67-131, M = 99.88±16.69 or Perceptual Organization Index or Perceptual Reasoning Index (POI/PRI; 69-128 M =101.00±16.92). All participants had obtained a high school diploma, 6 had also completed some college courses, and 3 others had obtained bachelors and post-graduate degrees. Inclusionary criteria for participants with AgCC consisted of MRI scan verification of a complete or partial absence of the corpus callosum, and an FSIQ of at least 80. Exclusionary criteria included English as a second language, history of moderate-to-severe head injury, major CNS disorder not associated with AgCC, intractable epilepsy, drug abuse as assessed by clinical interview, and structural brain abnormality other than that which is typically found in AgCC (e.g., colpocephaly, Probst bundles). Out of 20 individuals enrolled in this study, three were eliminated due to presence of additional neuropathology (asymmetric volume of frontal lobes,

heterotopic gray matter in right frontal lobe & large inter-hemispheric cyst, globally diminished size of left hemisphere and heterotopic grey matter in anterior horn of left lateral ventricle) and one was eliminated due to intractable epilepsy. In review of the 15 (of the remaining 16) MRI scans that were available for evaluation, the anterior commissure was visible in all 15 and posterior commissure was visible in 14 scans, indicating that commissural malformation was isolated to the corpus callosum. For one participant, AgCC diagnosis and absence of additional neuropathology was verified by MRI report, but we were unable to directly review the scan to identify the presence or absence of additional commissures (which are not commonly included in a clinical report).

All participants were selected and recruited from a group of individuals who had previously been tested at the Travis Research Institute Neuropsychology Lab. Prior to testing, participants were emailed a consent form which they were to sign and mail back if they were willing to participate in the study. All participants were compensated $20 for completing an on-line version of the MSCEIT. The protocol utilized in this study was reviewed and approved by the Human Subjects Research Committee at the Fuller Graduate School of Psychology.

Measures

The Mayer-Salovey-Caruso Emotional Intelligence Test, Version 2.0 (MSCEIT V2.0; Mayer et al., 2002) is comprised of 141 items, distributed into 8 subtests. Subtests are combined into four branch scores (each comprised of two subtests). Additionally, the four branches of the MSCEIT can be grouped into two primary areas, with the first two branches (Perceiving and Using) comprising the Experiential EI Area, and branches 3 and 4 (Understanding and Managing) making up the Strategic EI Area. The first branch, Perceiving Emotions, is comprised of a task involving the perception of emotions in faces, and another task related to judgment of

the emotion conveyed through pictures of landscapes and abstract designs. Branch 2, Using Emotions (to facilitate thought), is comprised of a sensations task and a facilitation task. In the sensations task, the participant is asked to internally generate a particular emotion and rate the experience on a 5-point scale with respect to the degree to which the given emotion matches a physiological sensation (e.g., how hot or cold the emotion of anger feels). For the facilitation task, participants must decide (again on a 5-point scale) how well an emotion might help to facilitate or aid in carrying out a particular behavioral or cognitive task.

Understanding Emotions, branch 3, consists of blends and changes subtests. On the blends task, participants must select two emotions that best combine to form a more complex emotion (e.g., anger and disgust combine to form the emotion of contempt). In the changes task, participants are asked to choose the best emotion that results from either the amplification of another feeling or a change to a different emotion depending on the context of the scenario given. Managing Emotions, branch 4, is comprised of the emotional management and social management tasks. In the emotional management task, participants must identify the actions that would be best for them to take in order to manage their *own* emotions if they were presented with the situation faced by an individual in a fictional story. The social management task asks participants to evaluate which actions would be best to undertake in order to help manage the feelings *of another person* in a particular scenario.

The MSCEIT scoring system used in this study was the *general consensus* scoring method, with standard scores based on gender and age. Norms were derived from responses gathered from a sample of 5,000 participants predominantly from the U.S., but also includes samples from the United Kingdom, Canada, Malta, South Africa, Australia, Switzerland, Scotland, the Philippines, India, Slovenia, and Sri Lanka (Mayer et al., 2002). A weighting

scheme developed from this larger sample is used to compute standardized norm scores based on an ideal U.S. demographic representation according to gender, age, ethnicity, and education. Internal reliability is .93 for full scale EI, .90 for Experiential EI, .88 for Strategic EI,.91 for Perceiving branch, .79 for Facilitating branch, .80 for Understanding branch and .83 for Managing branch (using general scoring; Mayer et al., 2002). Confirmatory factor analysis has validated the four branch structure in participants from the United States (Mayer, Salovey & Caruso, 2004).

Procedure

All participants received the Multi-Health Systems (MHS) Assessment online MSCEIT administration. Participants completed the MSCEIT remotely (from home). In order to access the test, each participant with AgCC had a prearranged phone call with the examiner. During the call, the examiner provided a UserID and password and answered any questions as the participant initiated the test. Following any clarifications given by the administrator, participants were instructed to call as soon as they had finished the test or if they encountered any difficulties during the process of taking the test. Participant test results were scored through MHS using age and gender controlled norms from the general consensus sample.

Statistical Analyses

The AgCC group's standardized MSCEIT test scores were compared to the normal curve of the general public sample. One-sample t-tests were conducted to test the significance of the difference of the group mean from a standard score of 100 in order to evaluate the hypothesis that the AgCC group would have significantly lower total EI, area EI, branch, and subtest scores than the normative sample. Bonferroni correction for multiple comparisons was applied to *p*-

values at each level of MSCEIT scoring. In additional, repeated-measures ANOVAs were used to examine the differences in scores across the areas and branches within the ACC group.

Results

Table 1 presents descriptive statistics of the group standard scores for Total EI, Area, and Branch scores, as well as the results of statistical comparisons to a standard score mean of 100 and the number of participants who scored 1.5 standard deviations above or below the mean.

Mean Total EI of the AgCC group did not differ significantly from the normative group mean. Nevertheless, in the primary areas, the participants with AgCC scored significantly lower than the norm on Strategic EI (t = -3.88, p = .003), but did not differ in Experiential EI (t = 2.42, ns). Furthermore, a repeated-measures ANOVA revealed that these participants with AgCC performed significantly lower on Strategic than Experiential EI ($F(1, 15) = 91.38$, $p < .001$, $\eta_p^2 = .86$). With respect to the branch scores, the AgCC group scored significantly lower than the normative group on Managing Emotions, (t = 3.67, p = .004), but did not differ from norms on Perceiving, Using, or Understanding Emotions. Repeated measures analysis across the branches showed a significant decline in AgCC group performance from Perceiving to Managing Emotions ($F(3, 45) = 18.91$, $p < .001$, $\eta_p^2 = .59$). Post-hoc analyses demonstrated that participants with AgCC group performed significantly worse on the Understanding branch compared to the Perceiving ($p = .001$, $\eta_p^2 = .51$) and Using ($p < .001$, $\eta_p^2 = .63$) branches; similarly, their performance was significantly lower on the Managing branch compared to the Perceiving ($p < .001$, $\eta_p^2 = .81$) and Using ($p < .001$, $\eta_p^2 = .71$) branches. In contrast, AgCC group scores did not differ between the Experiential Area branches (i.e., Perceiving and Using Emotions, $p = .70$, $\eta_p^2 = .01$) or between the Strategic EI branches (i.e., Understanding and

Managing Emotions, $p = .31$, $\eta_p^2 = .07$). This illustrates that the pattern of AgCC performance on the MSCEIT is characterized by a drop off in performance from the Experiential to Strategic Area (see Table 1).

Descriptive statistics for all subtest scores appear in Table 2 and Figure 1. Post-hoc analyses for subtests comprising the Managing Emotions branch indicated that the AgCC group scored below norms for both emotion management, ($t = -2.51$, $p = .048$, and social management, ($t = -3.40$, $p = .008$), but only social management survived correction for multiple comparisons. Examination of the remaining subtests (correcting for multiple comparisons) found no difference from norms on faces, pictures, sensations, changes, or blends, but the AgCC group scored *above* norms on facilitation *(*$t = 3.44$, $p = .008$).

Based on normal distribution of scores in a group of 16 participants, elevated or impaired scores would be expected in a maximum of only one participant. More participants than expected had impaired scores on Understanding Emotions (n=2), Managing Emotions (n=3), Strategic EI (n = 3) and Total EI (n = 2), and more than expected had elevated scores on Experiential EI (n = 2) (See Table 1). The 2 participants with impaired Total EI were also impaired on Strategic EI and Managing Emotions, but only one of them was also impaired on Understanding Emotions. A third participant was impaired on Strategic EI and Understanding Emotions, but not on Total EI. Finally, one participant was impaired on Managing Emotions only (not Strategic or Total EI). Two other participants with AgCC had elevated Experiential EI scores, one of whom was also elevated on Using Emotions, and there was a single participant with elevation on Perceiving Emotions only.

On subtests, the AgCC group had more participants than expected with elevated scores on faces (n=6, all > 2 SD above mean) and facilitation (n=5, 1 > 2 SD above mean), and more

participants than expected with impaired scores on social management (n=4, 2 > SD below mean) (See Table 2).

Exploratory analyses examined the correlations between MSCEIT scores and scores on WAIS-III (2 participants were excluded from this analysis because their IQ scores were acquired with the WISC-III at an earlier age than the MSCEIT). MSCEIT area, branch scores and 2 subtests of the Managing Emotions branch were not significantly correlated with FSIQ, VCI or POI (this remained true when controlling for complete/partial AgCC).

Discussion

The purpose of this study was to investigate the emotional functioning of individuals with AgCC through the use of the MSCEIT. Based on previous evidence suggesting deficits in AgCC on tasks related to recognition of emotions in others (Symington et al., 2010), expressions of emotions in narrative (Turk et al., 2009), and emotions in behavior (Badaruddin et al., 2007), we hypothesized that participants with AgCC would perform significantly worse on the MSCEIT in comparison to the standardized normative sample. Specifically, we expected that individuals with AgCC would score particularly low on branches and subtests that demanded more intense higher-order emotional problem-solving, i.e. significantly low scores in the Strategic area.

Overall MSCEIT scores were similar in the AgCC group compared to the normative distribution. However, this overall score masked robust differences in the pattern of branch and area scores with respect to norms. While the AgCC group did not differ from the normal distribution in the Experiential area, they scored significantly below norms in the Strategic domain, with lower than expected performance in the Managing Emotions branch. This outcome suggests that the capacity for experiencing and perceiving basic emotions is relatively normal in

adults with AgCC. However, adults with AgCC are unlikely to achieve typical levels of sophistication in considering strategies necessary for managing emotions.

Experiential Area

On average, the AgCC group performed above expectations in the Experiential area, and particularly the Using Emotions branch. This was reflected in performance on facilitation (a subtest of Using Emotions), which showed a tendency for persons with AgCC to perform significantly higher than expected. Generally, tests in the Experiential area involve more immediate, online judgments of perceived or felt emotions, or judgments regarding the immediate impact of emotion on behavior. For example, in the sensations subtest participants are asked to internally generate a particular emotion and rate the experience on a 5-point scale with respect to the degree to which the given emotion matches a physiological sensation (e.g., how hot or cold the emotion of anger feels). Normally distributed results on this subtest are consistent with previous evidence that persons with AgCC have normal physiological responses to emotionally salient images (Paul et al., 2006).

On an individual level, a greater number of adults with AgCC exhibited elevated scores in the Experiential Area overall, and the faces and facilitation subtests in particular. In the facilitation subtest, participants judge the extent to which a given emotion may facilitate or aid in executing a particular behavior or cognitive task (i.e., a judgment of the immediate impact of an emotion). The facilitation subtest does not appear to require analysis of social consequences, but rather relies mostly on understandings and memories of the impact of emotion on immediate thought and action.

Although judgment of emotion in faces was within normal limits for the AgCC group as a whole, there were more individuals with AgCC than expected who had elevated scores on this

subtest. In contrast, a previous study reported that judgment of emotion from faces was significantly poorer in adults with AgCC than a matched control group (Bridgman et al., 2014). The difference in outcomes may lie in the amount of time that participants were given to view the faces. In the previous study, faces were only shown for 1 second, but in the MSCEIT, faces are shown until the participant provides a response. During the 1 second presentation, persons with AgCC were found to be inefficient in their pattern of visual search, looking longer in the area of the mouth and nose than at the eyes. Use of longer viewing time in the MSCEIT provides greater opportunity to encounter critical facial cues such as the eyes and in turn, generate more accurate interpretations. However, because real-time social interactions require very rapid processing of emotional expressions, the previous study provides a somewhat more ecologically valid indication of face processing in social contexts.

Across the Experiential area, participants with AgCC were able to accurately perceive emotions and make judgments regarding the immediate impact of such emotions. Accurate perception and use of emotions is likely attributable, at least in part, to intact physiological experience of emotion (Paul et al., 2006). While the basic and immediate nature of emotional processing demanded within this area of the MSCEIT may require less in the way of interhemispheric interactions for successful outcomes, application of these skills may be significantly limited in real-time, rapid social interactions as was apparent in the studies by Bridgman et al. (2014) and Symington et al. (2010).

Strategic Area

As hypothesized, the AgCC group scored significantly lower than the MSCEIT norms in overall Strategic EI, and also lower than they scored for Experiential EI. In fact, 18% of the AgCC group (3 out of 16) scored more than 1.5 standard deviations below the mean in this area.

The AgCC group overall scored significantly below the standardized MSCEIT norms on the Managing Emotions branch and had greater than expected numbers of low scores in both Strategic EI area branches (Understanding Emotions and Managing Emotions).

Poor performance in Strategic EI suggests that individuals with AgCC may have diminished capacity either for reasoning abstractly about complicated socio-emotional situations, or for imagining social scenarios involving emotions. Thus, they have difficulty knowing how to manage effectively their own emotions and the emotional experiences of others. Much of the research examining the MSCEIT indicates that Strategic EI is an important predictive factor in social outcome, whereas Experiential EI is less critical to these areas of life (Matthews et al., 2012). Thus specific impairments in the strategic domain may contribute to the social problems reported for people with AgCC.

The reduced scores on Managing Emotions for these individuals with AgCC are primarily due to lowered performance on the social management subtest. The social management subtest involves conceptualizing complex vignettes and imagining how various behaviors might impact possible social outcomes, and might shape or alter the other's emotional expression. Thus, this task involves the ability to predict social and emotional consequences at multiple levels of a situation. It requires imaginative social simulations involving a theory of mind and the ability to empathize with the emotions of the other person, both of which have been found lacking in AgCC (Symington et al., 2010; Turk et al., 2009).

Recently, researchers have examined the neurological basis of ability-based EI such as tested by the MSCEIT. Barbey, Colom, and Grafman (2014) found MSCEIT scores were lowered in patients with damage to the grey matter of the right orbitofrontal cortex and left inferior and superior parietal cortex, as well as in those with damage to a number of white matter

tracks. Several other studies have documented a specific relationship between Strategic EI and the volume of the left ventromedial prefrontal cortex (Krueger et al., 2009) or damage in that area (Leopold et al., 2012; Killgore et al., 2012), as well as with volume in left posterior and anterior insula (Killgore et al., 2012). These regions are all part of an interconnected social cognition network, suggesting that the functioning of this network is critical to normal performance on tests of EI. Since these circuits involve bihemispheric interactions, callosal absence in AgCC would disrupt interhemispheric interactions between areas that are important to facilitating strategic social functioning.

Limitations in Emotional Processing in AgCC

The results of the current research provide greater clarity regarding the nature of emotional processing limitations in AgCC, which in turn informs our understanding of their social processing deficits. As indicated by a prior study, individuals with AgCC appear to have normal autonomic responses to emotional images (Paul et al., 2006), responses which may be critical for immediate, first-order judgments of emotions. Performance within the Experiential domain of the MSCEIT supports the conclusion that when given adequate time, adults with AgCC are able to distinguish between common emotions and label them accurately. Although they did not differ from norms as a group (after adjustments for multiple comparisons), the individuals with AgCC in this study were more likely than expected to attain elevated scores for judgment of basic emotion in faces and for their understanding of how emotions might impact (might hinder or facilitate) thoughts and behaviors. While these tasks involve immediate, first-order cognitive judgments, within the MSCEIT they do not occur under the time-pressure of real-life social interactions.

Performance of the AgCC group was significantly weaker in the Strategic area. Tests in this domain generally require more complex and second-order processing of information about emotions – either processing the nature of the relationships between situations and emotions, or imagining the strategic management of emotions within social contexts. The AgCC group had particular difficulty reasoning through scenarios that involved managing emotions of others. Social management involves simultaneous engagement of perspective taking and emotional processing. Thus, persons with AgCC appear to be deficient in complex and second-order cognitive processing of emotions.

This understanding of the nature of deficits in emotional intelligence in individuals with AgCC is parallel with our conclusion about the nature of deficiencies in language comprehension in persons with AgCC. We previously found that individuals with AgCC have normal capacities with respect to the comprehension of literal meaning in language, but were found to be deficient in comprehension in several domains of non-literal language, i.e., idioms, metaphors, proverbs and humor (Brown et al., 2003; Brown et al., 2005; Symington et al., 2010). Since these domains of deficiency in language were found to share in common a large portion of variance, we concluded that persons with AgCC had a core deficit in adequately comprehending the second-order (non-literal) meanings in language (Brown et al., 2005).

The outcomes of the MSCEIT suggest that there is a similar pattern with respect to the processing of social emotions. It is the second-order relations between emotions, and the higher-order complexities of understanding and managing the impact of emotions in social context that is notably weak in individuals with AgCC. Second-order processing requires imagination of meaning (in language) or situational possibilities (in social contexts) that are not explicit in the current stimulus situation. It seems as though individuals with AgCC have difficulty imagining

in a rich and complex way a hypothetical scenario which might foster better social and emotional outcomes, but further work is necessary to elucidate the role of imaginative processing in these deficits.

With respect to the role of the corpus callosum in these deficits in individuals with AgCC, we have hypothesized in the past that there are three possibilities that are not mutually exclusive. The first hypothesis is that second-order language and emotion processing is limited by significantly reduced interactions between the lateralized processing characteristics of the right and left hemispheres. In this interpretation, expressive language and more symbolic processing systems of the language-dominant hemisphere have significantly diminished input from the systems of the non-dominant hemisphere that are more specialized for emotion (including emotional prosody), facial expressions, broader semantic associations, and spatial awareness. A second hypothesis focuses more broadly on reduction of white matter and diminished cerebral connectivity. Absence of the corpus callosum would reduce the size of the neural networks that could be functionally interactive at any one time for any particular cognitive task – more complex cognitive tasks often requiring larger computational networks for rapid and efficient processing. While persons with AgCC have, perhaps surprisingly, preserved bihemispheric coordination of activity in the resting state networks, in the face of complex cognitive challenges callosal absence may render these systems less efficient. Consequently, this limitation in interconnectivity increases the time needed for cognitive processing (Marco, et al., 2012) and restricts capacity for more complex versions of cognitive operations (Brown & Paul, 2000).

Finally, it is conceivable that the deficits in social and emotional processing found in individuals with AgCC do not directly result from absence of the corpus callosum, but rather

result from cellular-level changes in cortical structure. For example, histological examination of brains from two deceased individuals with AgCC revealed fewer than expected Von Economo neurons (also called spindle neurons; Kaufmann et al., 2008). The cell bodies of these very large neurons are found mostly in the anterior cingulate cortex and fronto-insular regions of the brain, and they send their axons throughout the cerebral cortex. Given the location of these neurons, it is thought that they play a critical role in feeding emotional information in social situations to the cognitive processing systems of the cerebral cortex (Allman, Watson, Tetreault, & Hakeem, 2005). Thus, individuals with AgCC might have an additional neuropathology and associated processing deficiency involving reduced availability of basic social and emotional input to the higher-order processing networks of the cerebral cortex. Since these findings were based on only two persons with AgCC, the importance of this hypothesis in explaining deficiencies in the processing of emotion in AgCC must await further research.

Limitations and Clinical Implication

Study of unusual groups, such as persons with AgCC who function within the normal range of intelligence, limits the availability of research participants, and published research in such areas often involves relatively small sample sizes. Thus, the power of parametric statistics is not ideal. Nevertheless, comparisons in the current research were anchored in a very large control sample, and effect sizes were large.

This limitation notwithstanding, the results of this research highlight the fact that the difficulties in social and emotional processing faced by persons with AgCC occur at the level of higher-order cognitive processing related to situations involving emotions. It is the application and integration of information about their own emotions and the emotions of others into decisions regarding the most appropriate and effective behavioral responses that are difficult for

persons with AgCC. Thus, interventions are implicated that would involve explicit training regarding the most appropriate behaviors in different emotion-laden contexts.

The difficulties in managing emotions revealed by the MSCEIT are likely exacerbated in the time-pressured contexts of real-life social encounters. Thus, a limitation of methodologies involving off-line testing, such as the MSCEIT, is that the challenges faced by persons with AgCC are underestimated. Real-life contexts that demand strategic decisions about appropriate behaviors are faster moving, involve a wider variety of information to be appreciated and integrated, and involve a more nuanced variety of behavioral possibilities. Nevertheless, this research highlights the nature of the difficulties in social and emotional processing faced by persons with AgCC, and suggests a direction for the exploration of interventions and support that may be helpful.

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Table 1

Descriptive Statistics and Comparisons to Test Norms for Total, Area, and Branch Scores

	Mean (SD)	95% CI		*t* (15)	*p*	Imp (n)	BImp (n)	Elev (n)	BElev (n)
Total EI	96.76 (13.75)	89.70	102.80	-.943	.361	0	2	0	0
Experiential	107.62 (12.57)	101.65	113.47	2.42	.028	0	0	0	2
Perceiving	105.85 (12.38)	100.31	112.12	1.89	.078	0	0	1	0
Using	107.02 (11.71)	101.04	112.13	2.40	.030	0	0	0	1
*Strategic	89.15 (11.19)	83.14	93.73	-3.88	.0015	1	2	0	0
Understanding	92.72 (12.35)	87.20	98.70	-2.36	.0325	1	1	0	0
**Managing	89.24 (11.74)	82.98	94.12	-3.67	.0023	1	2	0	0

p = p-value not corrected for multiple comparisons; * significant corrected for multiple comparisons at $p < .025$; ** significant within post-hoc test corrected for multiple comparisons at $p < .025$; All significance values are in comparison to the MSCEIT test mean of 100; 'impaired' and 'elevated' scores differ from mean by more than 2 standard deviations; Imp = impaired; Elev = elevated; 'impaired' and 'elevated' scores differ from mean by more than 2 standard deviations; BImp = borderline impaired; BElev = borderline elevated; borderline scores scores differ from mean by more than 1.5 and less than 2 standard deviations

Table 2

Descriptive Statistics and Comparisons to Test Norms for Subtest Scores

	Mean (SD)	95% CI		*t* (15)	*p*	Impaired (n)	Elevated (n)
Faces	114.42 (25.44)	102.23	126.51	2.27	.039	0	6
Pictures	106.09 (11.42)	100.85	111.63	2.15	.050	0	1
*Facilitation	112.14 (14.10)	104.99	118.39	3.44	.004	0	5
Sensations	100.08 (12.20)	94.96	106.55	.0268	.979	0	1
Changes	96.19 (14.45)	89.88	103.51	-1.054	.308	1	0
Blends	93.41 (10.44)	87.95	98.08	-2.53	.023	1	0
Emotion Management	92.72 (1.61)	87.13	98.13	-2.51	.024	1	0
* Social Management	89.55 (12.30)	82.73	94.57	-3.40	.004	4	0

p = p-value not corrected for multiple comparisons; * significant when corrected for exploratory multiple comparisons p < .006; ** significant within post-hoc test corrected for multiple comparisons at p < .025; All significance values are in comparison to the MSCEIT test mean of 100; 'impaired' and 'elevated' scores differ from mean by more than 1.5 standard deviations

Figure 1

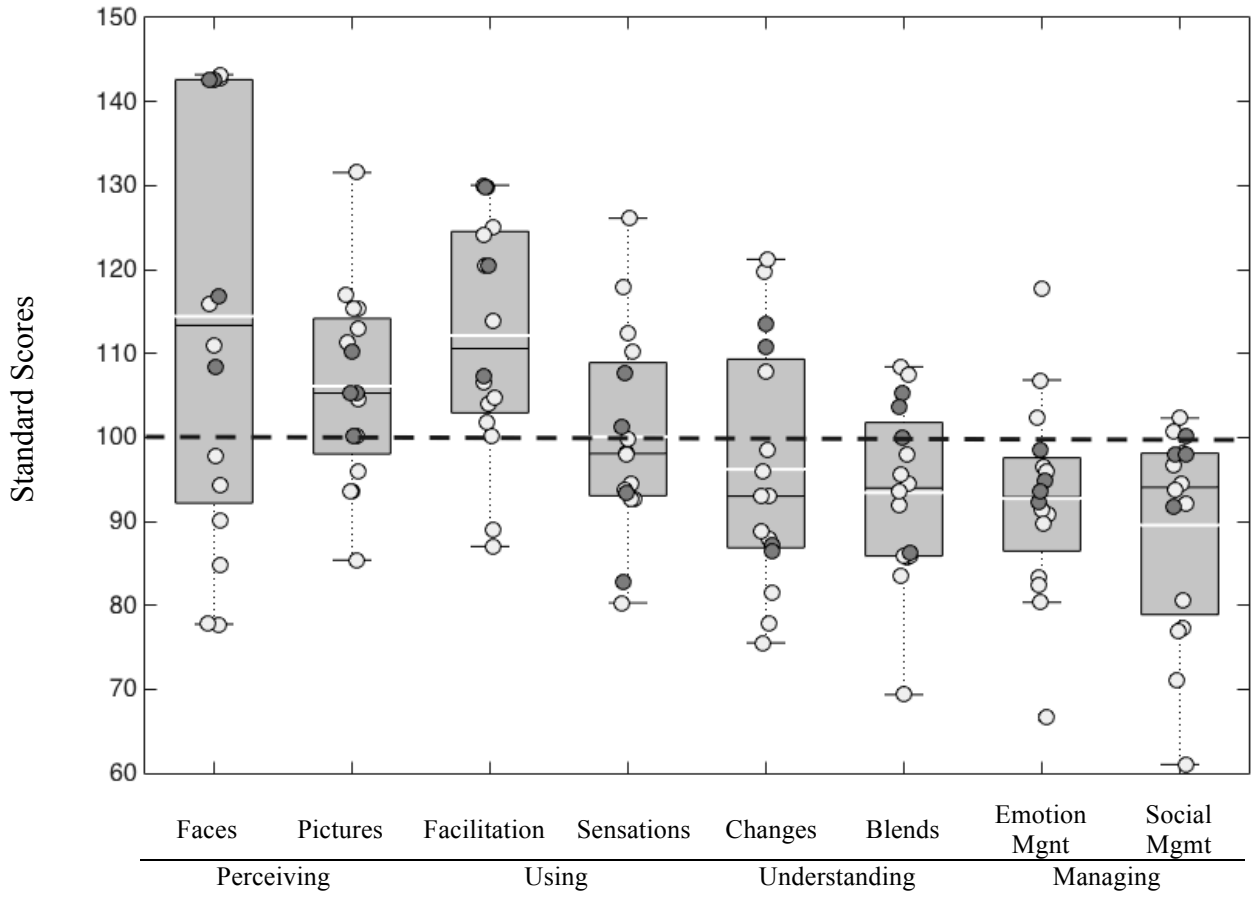
Standard Scores
150
140
130
120
110
100
90
80
70
60
Faces
Pictures
Facilitation
Sensations
Changes
Blends
Emotion Mgnt
Social Mgmt
Perceiving
Using
Understanding
Managing

Figure Legend

Figure 1. MSCEIT subtest scaled scores presented for all participants with AgCC as boxplots with individual participant scores overlaid (complete AgCC = light gray, partial AgCC = dark gray). Within the boxplots, black lines indicate median and white lines mean. Scores above the top dotted line and below the bottom dotted line are greater than 1.5 standard deviations from the normative mean.