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Social narratives in agenesis of the corpus callosum: Linguistic analysis of the Thematic Apperception Test

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ABSTRACT

In a previous study, individuals with agenesis of the corpus callosum (ACC) with normal intelligence provided narratives to pictures from the Thematic Apperception Test (TAT) that were limited in logical coherence and social awareness. The current study examined the linguistic content of TAT stories from 22 persons with isolated complete ACC compared to 30 IQ- and age-matched controls using the Linguistic Inquiry and Word Count (Pennebaker et al., 2001). Compared to controls, individuals with ACC used fewer words pertaining to emotionality, cognitive processes, and social processes. They also used relatively more present tense verbs and first person pronouns. These findings suggest that callosal agenesis results in deficiencies in imagining and inferring the mental, emotional, and social functioning of others as implied by TAT pictures, and in translating this content into a narrative. In addition, ACC affects the grammatical structure of verbally produced narratives, with greater emphasis on the present tense and the first person.

1. Introduction

Agenesis of the corpus callosum (ACC) is a birth defect that occurs in approximately 1 in 4000 births (Guillem, Fabre, Cans, Robert-Gnansia, & Jouk, 2003; Wang, Huang, & Yeh, 2004). ACC consists of failure of congenital development of the 200 million axons of the corpus callosum despite the absence of such a large connective structure, individuals with ACC can have normal-range IQs (Chiarello, 1980; Sauerwein & Lassonde, 1994). However, the consequences of ACC for both cognitive and social capacities are not yet well documented for those with an IQ in the normal range. The current study explored the nature of social cognition and social inference in adults, adolescents, and older children with ACC using linguistic analysis of stories told in response to pictures from the Thematic Apperception Test (TAT; Murray, 1943).

1.1. Cognitive and psychosocial deficits in ACC

Individuals with ACC have significant reductions in interhemispheric transfer, but do not show the classical split-brain syndrome (e.g., failure of visual or somatosensory interhemispheric transfer; Bogen, 1985). This may be explained by two very important differences between congenital callosal absence and the surgical split-brain. First, while classical split-brain surgery severs all interhemispheric connections, most individuals with ACC retain smaller cortical connections such as the anterior, posterior, and/or hippocampal commissures. Although the corpus callosum contains approximately 4000 times more neurons than the anterior commissure, in cases of callosal absence this small connection may become a primary route for interhemispheric communication. The anterior commissure connects important cortical areas of the temporal poles and medial prefrontal cortex in intact brains and it is possible that in ACC it gets recruited into multi-synaptic connections covering a broader cortical area. This latter possibility highlights the second major difference between commissurotomy and callosal agenesis: developmental age at onset. Although little is known about developmental plasticity in ACC, there is evidence that interhemispheric transfer in individuals who have a commissurotomy during early childhood is much more similar to what is seen in individuals with ACC than it is to the split-brain syndrome of people who have surgery in adulthood (reviewed in Paul et al., 2007).

There is, nevertheless, a growing literature of published studies that describe the cognitive limitations of individuals with ACC, but the pattern of consistent cognitive deficits has not been fully described. Our results thus far, and those appearing in the research literature, suggest that higher functioning adults with ACC typically have deficits in the following areas: interhemispheric transfer of complex sensory information and learning (Brown, Jeeves, Dietrich, & Burnison, 1999; Imamura, Yamadori, Shiga, Sahara, & Abiko, 1994; Jeeves, 1979; Jeeves & Silver, 1988; Karnath, Schumacher, & Wallesch, 1991; Mueller, Marion, Paul, & Brown, in press; Sauerwein & Lassonde, 1983); bimanual motor coordination

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(Jeeves, Silver, & Jacobson, 1988; Jeeves, Silver, & Milner, 1988); complex novel problem-solving (Gott & Saul, 1978; Sauerwein & Lassonde, 1994; Smith & Rourke, 1995; Solursh, Margulies, Ashem, & Stasiak, 1965); processing of subtle phonetic and semantic aspects of language (Dennis, 1981; Jeeves & Temple, 1987; Sanders, 1989; Temple & Ilsley, 1993; Temple, Jeeves, & Vilarroya, 1989, 1990); comprehension of the second-order meanings of language (Brown, Paul, Symington, & Dietrich, 2005; Brown, Symington, Van Lancker, Dietrich, & Paul, 2005; Paul, Van Lancker, Schieffer, & Brown, 2003); and psychosocial understanding and behavior (Brown & Paul, 2000; Paul et al., 2003). Since the individuals with ACC that we have studied have complete ACC, normal IQs, and few, if any, other structural brain abnormalities, we refer to this form of ACC as *primary ACC*. This pattern of cognitive and social deficits provides a preliminary definition of a *primary ACC syndrome*. In the context of this nomenclature, "ACC" would refer to the anatomical abnormality itself, which would include both those with primary ACC and those with other brain abnormalities and lower IQ. However, for the sake of brevity, the term "ACC" refers in this paper to "primary ACC" unless otherwise indicated.

Limitations in psychosocial behavior and understanding appear to be features of the primary ACC Syndrome, although this is a more difficult domain in which to establish deficiencies with confidence. Family members or friends of adolescents and adults with primary ACC often describe mild, but noteworthy, deficiencies in social functioning (Badaruddin et al., 2007). In a survey of parents of children with ACC (both complete and partial ACC, and including some of lower than normal IQ), O'Brien (1994) reported a tendency for these children to talk in clichés (although not to talk excessively or to be lacking in normal expressive inflection), to have poor social judgment, and to have difficulty understanding facial expressions. In addition, parents of children with primary ACC have indicated that they often miss the point of jokes and stories (Brown, Paul, et al., 2005).

A recent survey of parents of children with Primary ACC ($N = 61$), using the Child Behavior Checklist (Achenbach, 1991) and other questionnaires, documented the prevalence of problems in social functioning (Badaruddin et al., 2007). According to parent ratings, a statistically significant percentage (39%) of older children with ACC (between the ages of 6 and 11) had clinically significant problems (relative to test norms) with social behavior, 51% manifested problems in social communication, and 30% had problems with aggression. Also, clinically significant manifestations of thought problems were indicated in the parent ratings of 30% of the individuals with ACC. Younger children with ACC (ages 2–5) were not consistently rated as having problems in these domains. In this same study, a comparison group of children with autism showed a significantly greater proportion of individuals with clinically significant social problems (75%) and thought problems (75%) than the ACC group. Thus, while social and thought problems are manifest in ACC, they are not as likely to be as severe as those seen in children with autism.

Evidence for a relationship between the integrative function of the corpus callosum and emotional expression and cognition comes from early studies of commissurotomy patients that found that they had difficulty incorporating their own subjective feelings into the content of their speech—that is, alexithymia (Hoppe & Bogen, 1977). Brown and Paul (2000) found a similar absence of emotional content in the expressive language of both cases of ACC studies. In a case report of an individual with ACC, Sifneos (1973) noted that the patient exhibited seven of eight criteria of alexithymia, including poverty of emotional content in speech, tendencies to describe events rather than emotions, and impoverishment of fantasy life (Buchanan, Waterhouse, & West, 1980). Similarly, Ernst, Key, and Koval (1999) reported a case of an individual with ACC who demonstrated flat affect, restricted fantasy life, and an elevated score on the Toronto Alexithymia Scale. Brown and Paul hypothesized that deficits in the social domain may stem from the fact that absence of the corpus callosum prevents the right hemisphere from adequately communicating information regarding the correct emotional or social interpretation of information to the left hemisphere for verbal output. Thus, individuals with ACC or split-brain patients would have difficulty integrating all of the complex forms of social information and responding appropriately in speech.

An important contributor to social perception is an ability to infer and understand second-order meanings in conversation and other forms of discourse, such as the meaning of non-literal expressions and humor. Recent studies have demonstrated that individuals with primary ACC have deficits in the comprehension of both non-literal language (Brown, Symington, et al., 2005; Paul et al., 2003) and humor (Brown, Paul, et al., 2005). Compared to age- and IQ-matched controls, these deficits were more striking in adults than in children (Brown, Symington, et al.). Deficits in the comprehension of non-literal meanings in language and in the appreciation of humor found in adults with primary ACC appeared to be similar to deficits seen in adults with damage to the right cerebral hemisphere (Paul et al., 2003).

The ability to correctly infer the mental states of other individuals, which has often been referred to as a Theory of Mind (ToM) has also been investigated in persons with ACC. Earlier studies of younger children with ACC did not find deficiencies compared to age peers on ToM tasks used with younger children (Temple & Vilarroya, 1990). Our study of ToM suggests that adults with ACC have difficulty interpreting the mental states of others, at least when the social information is more complex, more life-like (as when presented through video vignettes vs. paper and pencil tests), and extended over time (Symington, Paul, Symington, Ono, & Brown, in press). Similarly, individuals with ACC (like individuals with autism) are significantly less likely than controls to infer mental states and processes in their recounting of the animated interactions of simple triangles (Kang, 2008).

As already suggested, studies of observed behavioral disorders, non-literal language, and social cognition typically show less severe deficits for children with ACC than those seen in adolescents or adults with ACC (e.g., Badaruddin et al., 2007; Brown, Symington, et al., 2005; Temple & Vilarroya, 1990). We have generally presumed that younger children with ACC appear to be more normal than adolescents or adults with ACC because comparison samples of normal children have an immature corpus callosum that may not yet contribute to the cognitive capacity being tested (Hagelthorn, Brown, Amano, & Asarnow, 2000). Thus, on some tasks, there is no appreciable difference between young children with a normal but immature corpus callosum and children with ACC (e.g., Chicoine, Proteau, & Lassonde, 2000). However, adults, adolescents, and older children with a normal corpus callosum would benefit from callosal maturity and thus perform such tasks significantly better than similar aged persons with ACC (e.g., Jeeves, Silver, et al., 1988). An alternative but not mutually exclusive possibility is that younger children unaffected by ACC can make significant use of their as yet immature corpus callosum, even though this capacity is not yet fully called into play by the cognitive demands of their daily environment.

1.2. Linguistic analysis of the TAT

In a previous study, the narratives provided by 5 adults with Primary ACC and their matched controls in response to six TAT pictures were analyzed using a blind rating system that assessed three elements of the story narratives: story logic, social understanding, and common content (Paul, Schieffer, & Brown, 2004). Individuals with complete ACC were all found to be significantly impaired on all three criteria, as compared to the controls. However, while

these results are generally revealing regarding deficits in social perception and/or social inference in ACC, it was not possible to tell from these results what specific semantic aspects of the narratives were deficient—only that they were globally unusual with respect to story logic, social understanding, and common content.

In order to more fully assess differences in the characteristics of TAT narratives of individuals with ACC, the current study used the Linguistic Inquiry and Word Count system (LIWC2001; Pennebaker, Francis, & Booth, 2001) to obtain quantitative information about linguistic and semantic content. The LIWC analyzes text by counting words that can be classified with respect to major linguistic dimensions (e.g., unique words, words longer than six letters, pronouns, articles, prepositions); categories related to time, space, or motion (e.g., past, present, or future tense verbs); four major domains of psychological constructs (Affective or Emotional; Cognitive; Sensory/Perceptual; and Social); and five areas of personal concerns (Occupation; Leisure activity; Money and Financial issues; Metaphysical issues; and Physical States and Functions).

LIWC was designed to investigate linguistic features of writing about traumatic experiences in order to try to predict subsequent health improvements (Pennebaker et al., 2001). Research on the external validity for LIWC scales was conducted on written samples from Dartmouth freshmen (Pennebaker & Francis, 1996), with judges rating samples according to various dimensions corresponding to the LIWC scales. Relatively high correlations were obtained. Feedback from several dozen studies led to a significant revision of the system (LIWC2001). Subsequently, text from 43 separate studies were analyzed and compared, and the LIWC2001 was able to tag and classify an average of 80% of the words that people used in these samples of writing and speech. In a study of responses to TAT cards, Pennebaker and King (1999) compared LIWC factors with ratings of content related to achievement, affiliation, and power, and found that LIWC language factors were able to predict the outcome of the ratings. LIWC has also been used successfully to detect and characterize self-reflective thought and social connectedness in autophotographic essays (Burke & Dollinger, 2005), as well as social isolation as reflected in the poems of suicidal poets (Stirman & Pennebaker, 2001).

1.3. Research goals

This research used the LIWC2001 as a tool to analyze the linguistic and semantic content of responses to six TAT picture stimuli from adults, adolescents, and older children with ACC compared to age- and IQ-matched controls. It was hypothesized that the TAT protocols of the ACC group would contain thematic content that would differ significantly from the protocols of controls—specifically, that there would be fewer expressions of emotion, social interactions, and cognitive processes of the characters in the TAT narratives of individuals with ACC. We also hypothesized that, compared to controls, the grammatical structures used by individuals with ACC would be indicative of less complex story structure (e.g., fewer overall words in various grammatical categories, and a different distribution of words among categories).

2. Methods

2.1. Participants

Two groups of participants were tested: 22 individuals with Primary ACC (16 male and 6 female) and 30 non-ACC controls (25 male and 5 female). Individuals with ACC ranged in age from 8 to 31 years ($M = 15.7$; $SD = 7.1$), and had IQs in the average range, from 83 to 122 ($M = 93.2$; $SD = 9.6$). ACC was confirmed by MRI in all cases except one, for whom ACC was diagnosed from a CT scan. A test of handedness (Edinburgh Handedness Inventory; Oldfield, 1971) indicated that 14 of the individuals were right-handed, and 8 were left-handed (using the standard criterion of a score exceeding 40 for right-handed, and −40 for left-handed). Three were taking a psychoactive medication (i.e., Ritalin, Depakote, or Dilantin).

Controls were recruited from community college psychology courses or from local employment agencies, or were selected from school populations. Individuals were selected to roughly match the IQ and age of participants with ACC. The IQs of the control group ranged from 83 to 120 ($M = 95.7$; $SD = 8.0$) and their ages ranged from 8 to 34 years ($M = 16.0$; $SD = 7.0$). There were no significant differences between the ACC group and the controls in age, $F(1, 51) = 0.02$, $p = .886$, or IQ, $F(1, 50) = 1.00$, $p = .322$. In this control group, 26 individuals were right-handed and 4 were left-handed.

The inclusion criteria for all the participants were the following: Full Scale IQ of 80 or above, native English speaking, and participation in mainstream education (although some individuals were involved in special education classes). Exclusion criteria were: history of major head trauma; history of neurosurgery or central nervous system disease; history of more than two seizures; history of major psychopathology; or taking psychoactive or other medications that might interfere with TAT performance. In addition, individuals with ACC were excluded if they had other major brain abnormalities evident in the MRI (other than colpocephaly or small interhemispheric cysts, both of which frequently accompany complete ACC).

2.2. Procedures

Cards 1, 2, 6BM, 8BM, 12M, and 13MF from the TAT were chosen for their potential to elicit social inference and emotional expressiveness in narrative responses. According to the standard TAT administration protocol, participants were shown the cards one at a time and asked to tell a story for each card. Specifically the administrator said, "For the next test, I'm going to sit next to you. I am going to show you a series of pictures. For each picture, I want you to tell me a story with a beginning, middle, and end. Tell me what the characters are thinking, feeling, and doing. And make sure you tell me how it ends." The examiner wrote down the stories verbatim. When the participant indicated that the story was finished, queries were used to prompt for any of the six elements that had not already been spontaneously provided, according to the standard administration procedures (e.g., "What are the characters thinking?" or "How does the story end?"). For the analyses of this research, however, all portions of the stories that were elicited by queries were discarded so that only spontaneously generated speech provided prior to the use of queries was used. This was done in order to avoid the possibility of analyzing verbal content generated on the basis of demand characteristics, such as emotion words in response to a query about how characters were feeling. Of the stories told by individuals in the control group, 84% of stories where followed by a query of some kind, whereas 95% of the stories told by individuals with ACC were queried.

2.3. Data analysis

Narratives for each card were transcribed for computer analyses. Queries and comments made by the tester were removed, as well as word fragments (e.g., "umm" or "ah") and comments not relevant to the story. Contractions were changed (e.g., "don't" to "do not"). Oral-speech idioms were modified so as to be grammatically correct (e.g., "gonna" to "going to," or "mom" to "mother"). Transcribed stories were entered into the LIWC2001 program.

As noted previously, the LIWC2001 analyzes text by counting words that can be classified with respect to various grammatical and semantic dimensions. The number of words in each category and theme was tallied for each card for each participant. The *relative frequency per story* of these word-types (with respect to the total number of words used in the particular story) was used in the statistical analyses in order to account for individual variations in word generation. To examine the grammatical characteristics of the stories, we analyzed LIWC data for the following dimensions: adjectives, adverbs, auxiliary verbs, negatives, words longer than 6 letters, types of pronouns (1st person, 2nd person, or 3rd person), articles and prepositions, and verb tense (past, present, or future). Group differences were analyzed for each of these dimensions using MANCOVA (comparing each subject and story over multiple LIWC dimensions) with IQ and the square root of age used as covariates. The square root of age was used in order to take into consideration the fact that differences in corpus callosum maturity and cognitive capacities are more pronounced between children of different ages than they are between adults of differing age.

LIWC2001 (Pennebaker et al., 2001) also groups the word stems (stripped of prefixes and suffixes) according to their semantic meanings. For this study we focused on the 44 LIWC themes related to Psychological Processes and Personal Concerns. LIWC groups those 44 themes into 9 semantic categories, which we used to examine the socially relevant semantic content produced by our subjects.

A 2 (Group) by 9 (LIWC Semantic Category) by 6 (TAT Card) analysis of variance was first used to determine if the proportion of words falling into the nine Semantic Categories were able to discriminate between the semantic contents of the stories elicited by the six TAT cards (i.e., to see if there was a Card by Semantic Category interaction). In addition, this analysis revealed whether the participant groups differed with respect to their use of words within the different categories. This ANOVA was repeated, taking age and the square root of IQ as covariates.

Finally, we conducted a series of additional between-group ANOVAs to examine data from the subcategories of the Emotional and Social semantic categories.

Table 1
Mean percentages of words in various grammatical categories for the ACC group versus their matched controls.

Grammatical category	ACC[a]	MC	*F*	*F*[b]	eta^2
>6-Letter words	10.2 (5.9)	11.0 (5.4)	1.82~	3.32*	.03
Adjectives	8.5 (2.5)	9.4 (2.8)	1.44	1.06	.06
Adverbs	6.8 (2.5)	6.8 (2.5)	0.33	0.94	.12
Descriptive	1.3 (1.1)	1.5 (1.0)	0.63	2.04	.20
Negatives	1.2 (0.9)	1.5 (0.8)	0.93	2.36^	.13
Verbs: Auxiliary	6.2 (3.3)	6.5 (2.3)	0.11	0.15	.01
Past	4.6 (6.0)	5.8 (5.5)	3.85^	9.14****	.08
Present	13.3 (7.1)	12.9 (7.1)	0.43	8.00****	.07
Future	0.4 (0.8)	0.7 (1.4)	7.45***	6.55****	.06
Pronouns	13.8 (7.4)	15.1 (5.4)	2.80^	1.75	.02
1st person	1.0 (2.8)	0.3 (0.8)	9.62***	3.67*	.04
2nd person	0.3 (0.8)	0.2 (0.8)	0.42	1.50*	.02
3rd person	10.5 (5.6)	13.0 (5.0)	14.99****	5.94***	.06
Articles	9.0 (5.8)	7.1 (4.3)	7.05**	7.76****	.07
Prepositions	11.9 (5.3)	11.4 (4.1)	0.60	6.65****	.06

Note. ACC = Agenesis of the corpus callosum; MC = matched controls.
[a] Standard deviations in parentheses.
[b] *F* values and effect sizes with IQ and the square root of age as covariates.
~$p < .20$; ^$p < .10$; *$p < .05$; **$p < .01$; ***$p < .005$; ****$p < .0005$.

For the Emotional Processes Category, we analyzed results from the subcategories of Positive Emotions and Negative Emotions. For the Social Processes Category, we analyzed the subcategories of Communication, References to Others, Friends, Family, and Humans.

3. Results

3.1. General characteristics of stories

The ACC participants used an average of 83.6 words per story (*SD* = 114.5), of which an average of 86.7% (*SD* = 6.8) were tagged by LIWC2001 as dictionary words. The control group used an average of 62.1 words per story (*SD* = 38.1) with an average of 88.1% (*SD* = 6.4) of the words tagged. With IQ and the square root of age partialled out, the differences in story length were significant, $F(3, 270) = 12.05$, $p < .0005$. The standard deviations in words per story are widely discrepant, due largely to 2 verbose members of the ACC group whose story lengths were outliers. With the outliers removed, the means and standard deviations were much more similar between the two groups: $M = 53.4$ (*SD* = 41.2) for the ACC group and $M = 61.2$ (*SD* = 38.8) for the control group, $t(45) = 1.61$, $p < .10$. There was nothing otherwise remarkable about these two outliers (female, age 11, left-handed, FSIQ = 95; male, age 18, left-handed, FSIQ = 103). There was no difference in the percentage of words that were tagged by the LIWC2001 as being dictionary words, either with or without the outliers removed. Given that all further analyses were done using a percentage of the total words that were used, the outliers were not removed for subsequent analyses. Results of analyses using age and IQ as covariates are described below, although data without these covariates are reported in the tables.

3.2. Grammatical properties of narratives

Several significant differences between the ACC and the control groups emerged with respect to grammatical word categories and other non-semantic properties, even with the square root of age and IQ used as covariates (see Table 1). The ACC group used fewer words with more than six letters, $F(3, 305) = 3.32$, $p < .05$, and had a tendency to use fewer negatives, $F(3, 305) = 2.36$, $p < .10$, but used more articles, $F(3, 305) = 7.76$, $p < .0005$, and more prepositions, $F(3, 305) = 6.65$, $p < .0005$. Individuals in the ACC group used more first person pronouns, $F(3, 305) = 3.67$, $p < .05$, but less third person pronouns, $F(3, 305) = 5.94$, $p < .001$. Furthermore, there was also a highly significant difference in the use of past, present, and future tense verbs. Control participants used a significantly higher proportion of verbs in the past and future tenses than did individuals with ACC, $F(3, 305) = 9.14$ & 6.55, respectively, $p < .0005$, whereas the ACC group used more present tense verbs, $F(3, 305) = 8.00$, $p < .0005$.

Table 2
Group-by-semantic category-by-card analysis of variance.

Variable	*F*	*F*[a]	*eta*^{2}
Group	12.40*****	12.94****	.042
Card	6.32****	6.31****	.097
Group by card	1.30	1.30	.022
Semantic category	904.44*****	12.50****	.041
Group by semantic category	5.25****	5.39****	.018
Card by semantic category	8.50****	8.66****	.128
Group by card by semantic category	0.90	0.90	.015

[a] *F* values and effect sizes with IQ and the square root of age as covariates.
*$p < .05$; ***$p < .005$; ****$p < .0005$.

3.3. Semantic content

Differences in use of various semantic categories were tested using a 2 (Group) by 9 (LIWC Semantic Category) by 6 (TAT Card) analysis of variance (Table 2). For both groups combined, the semantic categories were differentially utilized across all cards, $F(8, 2360) = 12.50$, $p < .0005$. In addition, narratives for different cards elicited stories involving different proportions of the words that fall under the nine semantic categories, $F(40, 2279) = 8.66$, $p < .0005$. Separate category-by-card post hoc analyses for each group revealed significant differences in the distribution of words in semantic categories elicited by each of the six cards in both the control group, $F(5, 174) = 3.79$, $p < .005$, and the group with ACC, $F(5, 123) = 6.47$, $p < .0005$.

Within this same analysis of variance (group by semantic category by card), several group effects were detected (Table 2). The significant overall group effect, with age and IQ taken into consideration, indicates that a significantly smaller percentage of total words were categorized by LIWC2001 within the 9 Semantic Categories for the ACC group than for their matched controls, $F(1, 295) = 12.40$, $p < .0005$. The significant Group by Semantic Category interaction, $F(8, 288) = 5.39$, $p < .0005$, indicates that individuals with ACC tended to use a different pattern of semantic categories in their narratives than controls (see Table 3). Since the 3-way interaction was not significant, it can be concluded that the group differences in use of semantic category words were consistent over TAT Cards.

Table 3 presents the descriptive statistics and additional group comparisons for the 9 LIWC Semantic Categories. With the effects of IQ and the square root of age removed, we find that the ACC group used significantly smaller proportions of words from the categories of Social Processes, $F(3, 305) = 4.29$, $p < .01$, Cognitive Processes,

Table 3
Mean percentages of words in each semantic category for each group across all cards.

Semantic categories	ACC[a]	MC	*F*	*F*[b]	*eta*^{2}
Emotional processes	3.2 (3.7)	4.0 (3.0)	4.31*	3.83*	.036
Cognitive processes	5.5 (5.1)	7.1 (5.2)	7.47**	3.52*	.033
Sensory processes	2.9 (3.5)	2.8 (2.6)	0.23	0.43	.004
Social processes	18.4 (6.1)	20.7 (6.1)	9.98***	4.29**	.041
Occupation	1.8 (2.7)	1.9 (2.7)	0.09	0.16	.002
Leisure activity	1.9 (2.4)	1.7 (2.6)	0.68	0.81	.008
Money issues	0.1 (0.5)	0.3 (1.0)	2.54	1.37	.013
Metaphysical issues	1.3 (3.7)	1.3 (2.3)	0.03	0.96	.009
Physical states	2.1 (3.2)	1.8 (3.4)	0.63	1.12	.011

Notes. ACC = Agenesis of the corpus callosum; MC = matched controls.
[a] Standard deviations in parentheses.
[b] *F* values with IQ and the square root of age as covariates.
*$p < .05$; **$p < .01$; ****$p < .005$.

Table 4
Mean percentages of words for emotionality themes and social processing themes for the ACC groups versus their matched controls.

Variables	ACC[a]	MC	*F*	*F*[b]	*eta*^{2}
Affective or emotional processes					
Positive emotions	1.6 (2.4)	1.8 (2.3)	0.78	2.17$^{\wedge}$	.021
Negative emotions	1.6 (2.4)	2.1 (2.5)	3.92*	2.37$^{\wedge}$	.021
Social processes					
Communication	1.0 (1.7)	1.0 (1.8)	0.00	0.87	.008
References to others	11.0 (6.0)	13.3 (5.0)	13.21***	4.80***	.045
Friends	0.1 (0.6)	0.1 (0.6)	0.00	0.23	.002
Family	1.8 (2.6)	2.7 (3.4)	6.81**	5.29***	.049
Humans	3.9 (5.1)	2.8 (2.7)	6.08*	9.71***	.087

Notes. ACC = Agenesis of the corpus callosum; MC = matched controls.
[a] Standard deviations in parentheses.
[b] *F* values with IQ and the square root of age as covariates.
$^{\wedge}p < .10$; $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .005$.

$F(3, 305) = 3.52$, $p < .05$, and Emotional Processes, $F(3, 305) = 3.83$, $p < .05$.

When the word counts from the Emotion Semantic Category were divided into subcategories (Positive and Negative Emotions; see Table 4) there were only statistical trends for fewer emotion words for these subcategories among individuals with ACC. The Social Processes category is subdivided into words pertaining to Communication, References to Others, Friends, Family, and Humans—subcategories that are somewhat overlapping. Analyses of these subcategories over all cards indicated that the controls used significantly higher proportions of References to Others, $F(3, 304) = 4.80$, $p < .005$, and Family words, $F(3, 304) = 5.29$, $p < .005$, whereas individuals with ACC used a higher proportion of words pertaining to Humans in general, $F(3, 304) = 9.71$, $p < .005$.

4. Discussion

The aim of this research was to investigate the nature of social understanding and social imagination in individuals with ACC as reflected in narratives elicited by pictures from the TAT. Given indications from previous research that adults with ACC perform poorly on tests of social inference, have problems in social relations, have difficulty comprehending nonliteral language and humor, and show evidence of alexithymia, we predicted that ACC would be associated with diminished usage of words denoting social, emotional, and cognitive processes in TAT narratives.

Results of this study supported these predictions. Individuals with ACC told stories using significantly fewer words denoting emotional, cognitive, or social process, but were similar to controls in their use of words denoting more personal concerns (sensory processes, occupations, leisure activities, money, metaphysical issues, and physical states). In addition, the stories told by individuals with ACC utilized a different pattern of grammatical structures. They used more present tense verbs, and fewer verbs in the past or future tense. Compared to controls, individuals with ACC tended to produce narratives involving more use of the first person and less of the third person. As discussed below, these grammatical differences may also be a manifestation of difficulty inferring the perspective of other persons, as well as imagining social scenarios that might precede or follow the situations depicted in the TAT pictures.

It is important to note that the group differences in usage of the grammatical or semantic categories inventoried by LIWC2001, though statistically significant, were not without group overlap. While there is evidence that individuals with ACC may have impaired comprehension of second-order meanings in language, this study was not designed to examine specific linguistic deficits. The stimuli and task were chosen to challenge participants' capacity for rich story imagination and the process of story construction. Therefore, our interpretation of these data focuses on what they reveal about the social processing of persons with ACC, rather than on specific linguistic distinctions between the groups. The specific linguistic manifestations are not as clinically important as what they reflect in the social processing of persons with ACC.

4.1. Differentiation of TAT Card Themes using LIWC2001

An important finding of this study was confirmation of the sensitivity of LIWC2001 to differences in story content elicited by different TAT cards as evident in the significant Card-by-Semantic Category interaction. Different predominant ideas contained in narratives to different cards were reflected in greater or lesser numbers of words from different semantic categories. In a previous study, the Dartmouth adaptations of the General Inquirer content analysis computer program (a precursor to LIWC) was used successfully to compare response protocols from different TAT cards (Schnurr, Rosenberg, & Oxman, 1992). Confirmation of the finding that the LIWC2001 could reliably find thematic differences in responses elicited by the TAT cards is critical with regards to the assessment of differences found in LIWC2001 semantic categories between individuals with ACC and controls.

This outcome also suggests that TAT responses analyzed by LIWC2001 can offer a meaningful measure of social comprehension and social imagination in neuropsychological assessment. LIWC2001 overcomes the uncertainties in the analysis of TAT results that are associated with subjective psychological interpretations, allowing the TAT a place in neuropsychological research and assessment. The rationale for using the TAT in assessment of social processing is that the cards depict complex social interactions that normally elicit complex and nuanced recognitions and interpretations, as well as imagination of social process which might precede or follow what is depicted in the card. In addition, the nature of the typical response to each of these cards has been well established (Aronow, Weiss, & Reznikoff, 2001).

4.2. Semantic content in the narratives of ACC

With respect to comparing the narratives of individuals with ACC and controls, LIWC2001 analysis revealed a significant Group-by-Semantic Category interaction, but not a 3-way interaction. This finding indicates that individuals with ACC used a distinct pattern of semantic content in their stories that was relatively stable from card to card. Specifically, across all cards, controls used significantly more words in the Social Processes, Emotional Processes, and Cognitive Processes categories (see Table 3).

4.2.1. Emotion

As was hypothesized, individuals with ACC used fewer emotion words overall than their matched control group. This semantic category includes words such as "happy," "upset," "devastated," "excited," or "downhearted." Lesser use of emotion words is most clearly evident in diminished use of words denoting Negative Emotions (see Table 4). Given that the TAT cards are designed to elicit negative emotionality, this omission is important. For normal individuals, a typical story may begin with negatively charged semantic content, but then end up turning out well for the characters in the end (cf. Bellak & Abrams, 1997; Murray, 1938; Murstein, 1969). Individuals with ACC used words pertaining to emotionality not only less frequently, but also sometimes inappropriately given the context of the picture or the particular story being told by the participant. For example, one individual with ACC told a story about a man whose wife had died and was buried on the day of their anniversary, so he was "sad but a little bit happy."

One potential explanation for this outcome is that due to the absence of the corpus callosum, the language-dominant (typically left) hemisphere which is responsible for generating narratives has

reduced access to the emotional information in the non-dominant (typically right) hemisphere. Similar to our findings in ACC, several semantic analysis studies found that patients with surgical disconnection of the cerebral hemispheres expressed less emotional content in describing movie clips (Tenhouten, Hoppé, Bogen, & Walter, 1985a, 1985b, 1985c, 1986). Hoppe and Bogen (1977) related these findings to their hypothesis that a lack of interhemispheric communication in commissurotomy patients results in alexithymia, an inability to express emotions linguistically. Alexithymia has also been described in individuals with ACC (Brown & Paul, 2000; O'Brien, 1994; Paul et al., 2004). However, our current findings suggest that the deficits in emotional expression found in individuals with ACC may primarily relate to negative emotions.

The relative absence of expressions of negative emotion in TAT stories reported here is consistent with results from another study in which individuals with ACC were significantly less accurate than controls in naming negative emotions displayed by actors in video vignettes, but did not differ from controls in naming positive emotions (Symington et al., in press). The Valence-Specific Hypothesis of emotional processing suggests that the cerebral hemispheres are asymmetrically specialized, with negative emotions principally processed in the right hemisphere, and positive processed in the left (Adolphs, Jansari, & Tranel, 2001; Ahearn & Schwartz, 1979; Davidson, 1992; Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Wedding & Stalans, 1985). Since generation of verbal expression is typically lateralized in the left hemisphere, information about negative emotions must be transferred from the right hemisphere to left in order to produce accurate verbal descriptions about stimuli that involve negative emotions. As noted earlier, callosal agenesis greatly reduces capacity for transferring complex information between the hemispheres (Brown et al., 1999; see Paul et al. for review). Therefore, if acallosal brains have typical asymmetric specialization for processing language and emotions, then we would expect that limited interhemispheric transfer would result in impaired verbal expression of negative concepts, whether storytelling on the TAT or responding to questions about the emotional content of video vignettes. However, data are not yet available regarding functional specificity and asymmetry in the acallosal cortex.

4.2.2. Social processes

The TAT was chosen for this research because of its demands on social perception and inference that are inherent in the story-telling task. The deficiencies in social processing noted in previous studies of ACC (Brown & Paul, 2000; Paul et al., 2004; Rourke, 1989; Schieffer, 1999) also emerged in their TAT narratives. Individuals with ACC used fewer words in the semantic category of Social Processes, which would include words such as "mate," "talk," "they," or "child." In particular, persons with ACC tend to make fewer references in their stories to specific other persons or family members, and more non-specific references to indefinite persons, or Humans (see Table 4).

Difficulties in social perception and social inference with respect to the meaning of TAT pictures may be due to the inability of individuals with ACC to imagine social interactions that are not explicit, but rather implicit in the pictures (Brown & Paul, 2000). This lack of inference, imagination, and fantasy related to the social situations is characteristic of what Marty and de M'Uzan (1978, Original work published 1963) have described as "pensée opératoire,"—that is, thinking that consists largely of concrete details of surroundings and that is deficient in inference and imagination related to feelings or emotions. Indeed, one adult with ACC commented after she had responded to all the cards, that she was able to tell stories by thinking of events that had actually happened to her and talking about those situations. This type of deficit in imaginative thinking and creativity may be linked directly to deficient interhemispheric transfer. Based on study of commissurotomy patients, Bogen and Bogen (1988) concluded that the corpus callosum is necessary for creativity. Without such creativity, persons with ACC appeared to rely on broad generalizations from their own personal experience, but lacking in rich detail and references to particular persons.

4.2.3. Cognitive processes

Finally, individuals with ACC used fewer words denoting the inner mental process of the characters in their stories. This semantic category is denoted by words such as "know," "consider," "because," or "think." In essence, this category can be considered to reflect a Theory of Mind (ToM) or mentalizing—that is, inferring what others are likely to know or be thinking. The findings which suggest diminished mental inference in the narratives of individuals with ACC is consistent with results we have reported from more direct tests of social inference that demand ToM (Symington et al., in press). While deficits in ToM were not apparent when individuals with ACC were asked to provide verbal responses to written hypothetical scenarios, impaired social inference (and perhaps also ToM) was clearly present when the task involved interpreting video vignettes of social interactions. We hypothesized that these impairments emerged from a combination of difficulties in integrating information from multiple sources, using paralinguistic cues for emotion, and understanding non-literal speech.

A previous study found intact ToM in a small number of young children with ACC (Temple & Vilarroya, 1990). However, this prior study differs from ours (Symington et al., in press) with regard to both task (ours required more complex mental inferences) and population (ours was older, larger, and had higher IQ). Thus, although simple ToM may be intact in children with ACC, our study indicates that adults with ACC are likely to have difficulty inferring the mental processes of others in more complex social situations, which may represent a specific deficit in ToM, or a more general deficit in the capacity for inference and imagination.

4.3. Story structure and grammatical characteristics

The stories told by individuals with ACC tended to reflect more simplistic story structure and content, as well as different grammatical features than the stories of matched controls. Individuals with ACC used fewer long words (more than six letters), which may be related to their tendency to use more articles and prepositions; and they used fewer negatives (such as "no" or "not") than controls. Also, individuals with ACC were significantly more likely than controls to use first person pronouns and significantly less likely to use third person pronouns. This is congruent with the hypothesis that they have difficulty inferring the perspectives or histories of other persons, and thus find it difficult to tell a story from the perspective of another person. In order to comply with the story-telling task, individuals with ACC spoke more readily about something that the picture brought to mind about their own history or experience, often telling the story from the first person perspective. A typical example of a self-referential comment made by an individual with ACC was, "This is funny... I think that I know what he is doing because I used to play the same instrument."

Finally, our sample of individuals with ACC used fewer verbs in the past and future tenses than controls, and more verbs in the present tense. Concrete descriptions of the card (e.g., "there is a man lying there"; "there is a boy over here that is dressed"), lend themselves to the use of the present tense. Similarly, stories without a clear temporal narrative (i.e., without an imagined past and future) are told primarily using the present tense. This is further evidence of deficits in social and narrative imagination among those with ACC.

4.4. General characteristics of story-telling

Several other general characteristics of the story-telling of individuals with ACC were noted in this study. Telling stories that have "a beginning, middle, and end" did not seem to be a task that was as automatic and easily accomplished for individuals with ACC as it seemed to be for controls. In fact, when asked to tell stories, individuals with ACC tended to show some discomfort (e.g., fidgeting, or shuffling feet), often requiring encouragement to get started.

An indication of the difficulty experienced by individuals with ACC was their tendency to use more "fillers" (e.g., commentary about the cards rather than a story about the characters on the card) than the matched controls. For example, before starting his stories, a 14-year-old boy with ACC made comments such as "This looks like more of a painting. . . I am just examining it" or "Oh my God, I don't know, I can't figure out this story." These fillers were not included in the analyses of responses, so they did not contaminate results of the semantics of the story itself.

In addition, the story-telling of individuals with ACC seemed to contain more repetitions of phrases or concepts, particularly in response to queries. Importantly, in this study much of the repetition was removed by truncating stories at the first query, making it considerably less likely that numbers of words in theme headings were inappropriately elevated due to the repetitious nature of some stories. However, redundancy in response to queries reflects a limited ability to expand upon a narrative or to imagine more details, even when cued to do so.

5. Conclusions

The results of this study further illuminate the nature of the social processing deficits which often result from congenital absence of the corpus callosum. Specifically, it appears that a complete and normally functioning corpus callosum makes an important contribution to the process of inferring and imagining the social and emotional context surrounding pictures involving people in interactive situations, and to the translation of this content into a narrative. Individuals with ACC produced narratives deficient in words denoting emotions, social interactions, and the mental states of characters. Failure of imagination also appeared to influence the grammatical structure of narratives, with somewhat greater emphasis on the present tense and the first person than was the case for stories told by individuals in the control group. Finally, this study also demonstrates that TAT response protocols can be objectively scored in a meaningful way using LIWC2001 in ways that reveal differences in social cognition.

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