Decision-Making in Individuals with Agenesis of the Corpus Callosum: Expectancy-Valence in the Iowa Gambling Task

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Abstract

Individuals with agenesis of the corpus callosum (ACC) can have intelligence within the normal range, but nevertheless have deficiencies in decision-making and complex novel problem-solving. The specific nature of these problems is not yet clearly understood. The Iowa Gambling Task was used to test decision-making ability and problem-solving in 40 individuals with complete or partial ACC (full-scale intelligence quotient >80) and 26 control participants. The expectancy-valence (EV) model was applied to the trial-by-trial responses of each participant to elucidate differences in decision processes utilized by each group. The ACC group had a lower overall net gain and fewer advantageous choices than controls, but these differences were not statistically significant. Within the EV model, individuals with ACC exhibited significantly higher attention to losses, less consistency in their choice strategy, and greater frequency of switching between decks. They also showed a tendency to be more influenced by recent trials. This outcome is similar to that seen in individuals with Asperger’s disorder. Taken together, these results suggest that individuals with ACC have difficulty in inferring game contingencies and forming a coherent selection strategy, implicating the corpus callosum in these decision processes.

Keywords: Executive function; Problem-solving; Strategy formation; Loss aversion

Introduction

Agenesis of the corpus callosum (ACC) is a congenital disorder in which the corpus callosum does not develop (Jinkins, Whittemore, & Bradley, 1989). ACC is associated with mild cognitive disabilities, even when general intelligence is in the normal range. However, the exact nature and spectrum of these deficits is not yet entirely clear. Previously, we speculated that difficulty in complex novel problem-solving is a core deficit in ACC that lies at the root of other domains of cognitive and psychosocial disabilities (Brown & Paul, 2000). This study utilizes the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994) to ascertain more specifically the nature and extent of difficulties in problem-solving, strategy formation, and decision-making among individuals with ACC.

Agenesis of the Corpus Callosum

Recent epidemiological studies estimated that ACC occurs in approximately 1 in every 4000–5000 live births (Glass, Shaw, Ma, & Sherr, 2008; Paul et al., 2007). Callosal absence can be either complete or partial. Despite the callosal malformation, persons born with ACC may have a full-scale intelligence quotient (FSIQ) within the normal range, with only mild cognitive and behavioral deficits. Specifically, across many studies, individuals with ACC demonstrate relatively consistent impairments (mild to moderate) in the following domains: 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; Sauerwein & Lassonde, 1983; bimanual motor coordination (Jeeves, Silver, & Jacobson, 1988; Jeeves, Silver, & Milner, 1988; Mueller, Marion, Paul, & Brown, 2009); complex reaction time and cognitive process time (Brown, Jeeves, Dietrich, & Burnison, 1999; Brown, Thrasher, & Paul, 2001; Hines, Paul, & Brown, 2002; Marco et al., submitted); complex novel problem-solving (Brown & Paul, 2000; 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; Symington, Brown, Symington, Ono, & Paul, 2010; Turk, Brown, Symington, & Paul, 2010). The outcome of complete ACC has often been compared with the results of adult commissurotomy. These “split brain” patients have had all of the cerebral commissures surgically severed, and thus they are unable to complete even simple interhemispheric transfer tasks (Zaidel & Sperry, 1977). In contrast, persons with ACC often are missing only the corpus callosum, and other cerebral commissures are intact (e.g., the anterior commissure). The presence of other commissures, the ability to perform some tasks requiring interhemispheric transfer is preserved in ACC provided stimulus information is simple and easily encoded (Brown et al., 1999, 2001). For example, Brown and colleagues (2001) demonstrated that individuals with ACC are as susceptible as controls to the interhemispheric Stroop interference effect, suggesting that other cerebral commissures present in the majority of cases of ACC (such as the anterior commissure) allow for the interhemispheric transfer of information sufficient to mediate the color-word interference effect. Nevertheless, participants with ACC exhibit deficits in interhemispheric transfer when the information is more complex, and less easily encoded (Brown et al., 1999).

Cognitive Processing and Problem-Solving in ACC

A number of previous studies using small groups of individuals with ACC have suggested that deficiencies in problem-solving and reasoning are common among these individuals (Gott & Saul, 1978; Sauerwein & Lassonde, 1994; Smith & Rourke, 1995; Solursh et al., 1965). Brown and Paul (2000) gave an extensive battery of tests to two adolescents with ACC who had FSIQ in the normal range and concluded that problems in complex novel problem-solving seemed to be a core deficit. Schieffer (1999) and Schieffer, Paul, and Brown (2000) supported this conclusion in a group of eight individuals with ACC. Although individuals with ACC performed normally on the Wisconsin Card Sorting Task, they performed significantly worse than controls on the Halstead Category Test and the Number and Letter Sequencing, suggesting that the problem-solving deficit in ACC may only be evident on particularly complex tasks (see also Symington, 2004; Symington, Paul, & Brown, 2004).

Problem-solving and reasoning limitations in ACC may also contribute to deficits in the ability to infer and understand the second-order meanings in language. Impaired ability to recognize and interpret the second-order meanings results in deficient comprehension of non-literal language and proverbs (Brown, Symington, et al., 2010; Paul, Van Lancker, Schieffer, & Brown, 2003), as well as difficulty in understanding humor (Brown, Paul, et al., 2005). Complex problem-solving and reasoning also contribute to the ability to correctly infer the mental states of other individuals, often referred to as a Theory of Mind. In a recent study, adults with ACC were found to have difficulty in interpreting the mental states of others, at least when the social information was more complex, extended over time, and life-like (i.e., when presented through video vignettes vs. paper and pencil tests; see Symington, Paul, Symington, Ono, & Brown, 2010). In addition, individuals with ACC (like individuals with autism) are significantly less likely than controls to infer mental states and intentionality when describing animated interactions of simple triangles (Kang, 2008).

Difficulty in inferring the mental states of other persons and comprehending the second-order meaning in language are also domains of difficulty in persons on the high-functioning end of the autism spectrum. Similarity between the cognitive and social problems present in ACC and high-functioning autism was demonstrated in a survey of parent observations of their children with ACC and autism (Badaruddin et al., 2007). Although less severe in ACC than in autism, both groups were rated by parents as frequently exhibiting abnormalities of attention, cognitive processes, and social interactions. Likewise, recent studies of adults with ACC have revealed a pattern of social and communication deficits that overlaps with autism spectrum diagnoses (Booth, Wallace, & Happé, 2011; Paul, et al. 2011). Further comparison of the cognitive and social symptoms seen in ACC versus high-functioning autism may provide insights regarding the relationship between impaired connectivity and developmental diagnoses involving social impairments.

The Iowa Gambling Task

Bechara and colleagues developed the IGT in order to simulate real-life decision-making in a game including monetary rewards and punishments, with uncertainty surrounding when these occurrences will transpire (Bechara et al., 1994). The
IGT requires participants to infer from trial-by-trial experience the monetary reward contingencies associated with picking cards from each of four decks. Thus, the IGT involves intuitive emotion-based decision-making, imitating real-life quandaries in which individuals are faced with novel and complex situations requiring them to engage in problem-solving and inferential learning and to develop relevant behavioral strategies.

In the original Bechara and colleagues study (1994), patients with damage to the ventromedial prefrontal cortex (VmpFC) exhibited significantly poorer performance on the IGT when compared with controls. The authors hypothesized that this was due to the fact that individuals with VmpFC damage were unable to appropriately assess the riskiness of decisions related to rewards and punishments. The finding of reduced anticipatory skin conductance responses in the patients with prefrontal damage implicated interactions between emotion and reason in successful performance on the IGT. Further studies have been done which demonstrate similar poor performance in patients with other forms of frontal lobe dysfunction (Clark, Manes, Antoun, Sahakian, & Robbins, 2003; Fellows & Farah, 2005; MacPherson, Phillips, Della Sala, & Cantagallo, 2009; Maia & McClelland, 2004; Manes et al., 2002).

The Expectancy-Valence Computational Model

In addition to the analysis of overall scores, computational modeling of IGT performance can provide more nuanced differentiation of specific cognitive and motivational dysfunctions evident in clinical populations. One such approach called the expectancy-valence (EV) model (Busemeyer & Stout, 2002) utilizes a trial-by-trial analysis to tease apart cognitive and motivation processes behind IGT behavior. The EV computational model isolates a learning parameter, a motivation parameter, and a choice consistency parameter, as well as a goodness-of-fit parameter. The learning parameter (also called recency) measures an individual’s tendency to focus more on recent outcomes. The motivation parameter reveals the participant’s attention to gains and losses. The choice consistency parameter indicates whether or not the individual is forming a consistent strategy for making decisions.

The EV model has provided insights regarding the patterns of specific problem-solving deficits that resulted in overall IGT impairment among various clinical groups. For example, IGT impairment in individuals with Huntington’s disease was characterized by limited dependence on recent trials and inconsistency across choices, despite typical scores on the motivation parameter (Busemeyer & Stout, 2002). In contrast, cocaine abusers, alcohol abusers, and sex offenders exhibited significantly low scores on the motivation parameter, ignoring large losses in favor of high rewards (Lane, Yechiam, & Busemeyer, 2006; Stout, Busemeyer, Lin, Grant, & Bonson, 2004), while inmates who had committed violent crimes displayed a significantly greater impact of recent trials on the learning parameter and made erratic choices according to the choice consistency parameter, similar to individuals with orbitofrontal lobe dysfunction (Yechiam et al., 2008). Thus, the EV model has been effective in characterizing different patterns of problem-solving and decision-making in different populations, all of whom exhibited poor overall performance on the IGT and poor decision-making in real-life settings.

In contrast to the populations described above, adolescents and young adults with Asperger’s disorder (AD) did not exhibit impairment relative to controls in overall IGT performance (Yechiam, Busemeyer, Stout, & Bechara, 2005; Johnson, Yechiam, Murphy, Queller, & Stout, 2006). Nevertheless, the AD group shifted more frequently between decks, resulting in significantly shorter run lengths. EV modeling revealed that, relative to controls, these individuals with autism spectrum disorder (ASD) exhibited a pattern of greater inconsistency across choices and heightened attention to losses, but typical scores on the learning parameter. In fact, 40% of the AD group focused solely on losses, compared with 14% in the control group. Thus, although overall performance on the IGT was intact, EV analysis showed that individuals with AD were highly attentive to losses and inconsistent in their behavioral strategy.

The IGT in ACC

Although deficits in decision-making and problem-solving have been observed in people with primary ACC, these deficits appear to differ from those seen in individuals with frontal lobe dysfunction. In contrast to the risky decision-making strategies employed by people with frontal lobe deficiencies, decision-making impairment among individuals with ACC appears to be due primarily to an inability to properly integrate large amounts of information, especially in new and complex social situations (Brown & Paul, 2000; Symington, 2004).

This research investigated IGT performance, and the EV components of motivation, learning, and choice consistency (strategy formation), in individuals with ACC. In light of the hypothesis that ACC results in difficulty with novel complex tasks, we expected that the group with ACC would lag behind controls in figuring out the task contingencies in the early trials. In addition, given the similarities in cognitive and social deficiencies between high-functioning individuals on the autism spectrum (including AD) and ACC suggested in Badaruddin and colleagues (2007), we hypothesized that participants...
with ACC would exhibit IGT performance similar to AD, characterized by intact overall IGT scores, with significantly greater attention to losses (motivation parameter), greater inconsistency on their choices (choice consistency parameter), and little difference relative to controls on the learning parameter (Johnson et al., 2006).

Methods

Participants

This study involved an experimental group of 40 participants with ACC ranging in age from 11 to 55 (M = 26.78, SD = 11.51) with FSIQ ranging from 78 to 129 (M = 96.80, SD = 13.54), including 13 women, 13 left-handed individuals, and 9 individuals with partial rather than complete ACC. The control group consisted of 26 participants (9 women and 3 left-handed) who ranged in age from 17 to 51 (M = 26.31, SD = 9.38) and with FSIQ from 84 to 113 (M = 99.65, SD = 7.62).

Participants with ACC were recruited through the ACC Network, the ACC Directory, and the National Organization for Disorders of the Corpus Callosum (NODCC), as well as a few via local physicians. Age- and IQ-matched control participants were recruited from local employment agencies and Internet advertisements. Exclusionary criteria for both groups were: (a) English as a second language; (b) FSIQ of <75; (c) history of major head trauma, neurosurgery, or major central nervous system disorder not associated with ACC; (d) comorbidity with an intractable seizure disorder; (e) moderate-to-severe psychopathology; and (f) currently taking psychotropic medications that might significantly worsen performance on the measures included in our test battery. For example, drugs such as phenobarbitol, carbamazepine, and topiramate would all slow processing speed and impede attention, and therefore would have caused participants to be excluded.

We were able to review magnetic resonance imaging (MRI) or computed tomography data from 35 of the ACC participants. ACC in the other five participants was established from clinical MRI reports, although the images were not available for secondary confirmation of the diagnosis. We noted the following incidence of associated neuropathology: heterotopia (n = 7) and interhemispheric cyst (n = 4). Five participants with ACC also had a history of tractable seizures, which were remitted with mono-therapy (use of a single anticonvulsant) at a low standard therapeutic dose. Anti-epileptic medications taken under these circumstances are known to have mild cognitive side effects, primarily related to fine-motor coordination and motor reaction time, but do not impact higher cognitive skills involved in our task (Loring, Marino, & Meador, 2007). Clinical history suggested the possibility of a mood disorder in nine participants (three were taking anti-depressants at the time of testing) and attention deficit hyperactivity disorder in four participants (three were taking stimulants at the time of testing). When used effectively, both stimulants (to treat ADHD) and anti-depressants will improve attention and executive skills that may otherwise be compromised by those diagnoses. As such, we expected that any impact of these medications would actually involve improved performance. No other medications were being taken by participants in this study and no participants were excluded due to medication-related issues. All of our participants with ACC had attended mainstream classes at least part of the time in school and at the time of testing education levels were as follows: not completed High School, n = 10; High School, n = 15; some college, n = 8; Bachelors degree, n = 3; graduate degree, n = 4. Education attainment was not available for control participants.

Adult participants read and signed an informed consent form prior to testing. In the case of participants younger than 18 years, a parent signed the consent form and the participant signed a statement of assent to participate. This research was approved by the Human Subjects Review Committee at the Travis Research Institute, Fuller Graduate School of Psychology. Tests results described in this paper were taken from a larger neuropsychological test battery. In addition, testing took place over more than a decade due to difficulty in finding participants with ACC. Thus, some participants in this paper (19 of 40 with ACC) were also included in various other papers describing results from this battery. Inter-test contamination in these individuals, if present, is that which would be normal in clinical neuropsychological test batteries.

Instruments

General intelligence was measured in the ACC group using the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1997) or the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991). Due to time constraints in testing, control participants were given the 4-scale Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The WASI is reliable in predicting WAIS-III scores (FSIQ r = .90; VIQ r = .88; PIQ r = .84; Strauss, Sherman, & Spreen, 2006).

The primary measure utilized in this study was the IGT (Bechara et al., 1994). In this task, the participant chooses 100 cards from four decks and each selection results in a monetary gain and sometimes also in monetary loss. The participant’s goal is to make advantageous selections from the four decks of cards in order to earn as much money as possible, while avoiding making disadvantageous selections that would result in losing money. The IGT involves fake currency ($5, $20, $50, and $100 bills), a
scoring sheet for the administrator to keep track of responses, and four decks of cards (labeled A, B, C, and D), each deck containing 40 cards. Twenty of the cards in each deck have a solid black face and 20 of the cards have a solid red face (cards are presented face down) that are arranged in a pre-set order prior to the task.

Decks A and B yield gains of $100 each time a card is selected whether black or red, but gains are offset by large losses when red cards are drawn. Thus, overall the outcome for these decks is disadvantageous. Losses occur 40% of the time when selecting from Deck A, with the losses ranging from $150 to $350. For Deck B, participants experience a loss only 10% of the time. However, one out of every 10 selections results in a $1250 loss, making it equally disadvantageous overall to select from Deck B as Deck A. Thus, on average, every 10 cards selected from either Deck A or B results in a net loss of $250 for participants, resulting in an overall loss of $1000 if participants choose to select all 40 cards from either deck.

Selecting a card from Decks C and D delivers a more modest gain of $50 for each selection, but the corresponding losses incurred are much lower than in Decks A and B. Selections from Deck C yield losses 40% of the time, but the losses range from $25 to $75. Only 10% of the cards in Deck D incur losses, but each loss in this deck is $250. In contrast to Decks A and B, choosing all 40 cards from either Deck C or D results in a net “gain” of $1000.

A participant’s overall score on the IGT was indicated by the total amount won or lost over 100 card selections. In addition, a decision bias score was determined, which was the difference between the number of advantageous and disadvantageous choices (number of selections from Decks A and B minus the number of selections from Decks C and D) calculated for each of five sequential blocks of 20 trials and for the entire 100 selections. Finally, the average length of runs of choosing from the same deck was calculated for each participant, as well as their longest run.

Procedure

Testing was done in 2–3 hour sessions, in some cases as a part of a larger test battery. Participants were initially administered the WAIS-III, WISC-III, or WASI (as appropriate) in order to determine their FSIQ. For the IGT, participant and administrator sat facing each other on opposite sides of the table. In front of the participant were the four decks of cards arranged in order from deck A on the participant’s far left to Deck D on the far right. Every deck was visibly labeled (“A,” “B,” “C,” or “D”) by a piece of paper placed behind the corresponding deck.

The administrator first read the instructions aloud to the participant. Participants were instructed to select one card on each trial from any deck and to place the card face-up in front of the deck from which they selected the card. They were informed that they were free to choose from any of the four decks as they wish. They were not told how many trials they would be asked to complete, but were instructed to continue to make selections until they were told to stop. Furthermore, participants were not informed about which decks were best, but only that certain decks were more advantageous to select from than other decks. Finally, participants were told that the goal of the task was to win as much money as possible, and to avoid, as much as possible, losing money. They were then given $2000 of fake money (eleven $100, fourteen $50, eight $20, and eight $5). After each selection, they were told how much they had won or lost, and the appropriate amount of money either given to, or taken from, the participant.

For each selection, the administrator wrote down on the scoring sheet the number of the trial in the box corresponding to the specific card of the deck chosen. The scoring of the test entailed adding up the total amount of money won or lost, calculating decision bias (the difference in the number of advantageous and disadvantageous choices) for the entire test and for each 20-trial block, and noting all lengths of runs of same-deck selections. Selection-by-selection data for each participant were subsequently entered into the EV computational model.

Statistical Analyses

Overall IGT scores include total overall winnings (in dollars), decision bias, average run length, and longest run. Decision bias ranges from −60 to 60 and is calculated by subtracting the total number of selections made from Decks A and B (disadvantageous decks) from the total selections made from Decks C and D (advantageous decks).

The EV computational model (Busemeyer & Stout, 2002) provided scaled scores for each participant on a goodness-of-fit parameter, a learning (or recency) parameter, a motivation parameter, and a choice consistency parameter. The goodness-of-fit parameter assessed how well the EV model captured the choice behavior of each participant. The learning parameter indicated the attention the participant paid to recent outcomes rather than the broader influence of all past trials. This parameter ranged from 0 to 1, with a higher score indicating greater recency effects. The motivation parameter represented whether the participant was more motivated by wins or losses. The motivation parameter ranged between 0 (attention only to gains) and 1 (attention only to losses). The choice consistency parameter indicated whether the participant made random selections throughout the task, or formulated and consistently utilized a specific strategy reflecting choice-outcome history. This score ranged between
+5 and −5, with positive scores indicating more consistent and strategic selections, and negative values indicating less consistent/strategic and more impulsive choices.

Overall scores (total gain/loss, decision bias score, average run length, and longest run) for the ACC and control groups were compared utilizing one-way analyses of variance (ANOVA’s). Given our hypotheses of deficits in complex, novel problem-solving in ACC, two repeated-measures ANOVAs (group by trial-block) were used to examine differences between groups on the decision bias scores: (a) over the first two 20-trial blocks, when the task was most novel (period of problem-solving and learning); and (b) for the last three blocks (period of more stable performance). The results of each of EV parameters were analyzed in separate ANOVAs due to numerical differences between these scales.

**Results**

A summary of descriptive statistics and IGT scores for ACC and control participants can be found in Table 1. There were no significant differences on either age (*t*(64) = 0.17, *p* = .86), FSIQ (*t* (62.94) = −1.09, *p* = .28), or gender ratio (*χ²* = 0.032, *p* > .50). As is typical of ACC, there was a higher rate of left-handed or ambidextrous individuals (*χ²* = 3.77, *p* = .05).

Group mean outcomes from playing the gambling game are summarized in Table 1. The ACC group lost more money on average than controls ($258 vs. $90), although the difference was not significant (*F*(1, 64) = 0.99, *p* = .32, *η²* = 0.02). Similarly, overall decision bias was not significantly different between groups (*F* (1, 64) = 0.21, *p* = .65, *η²* = 0.003). Both groups made a similar proportion of advantageous choices on the IGT overall, with the ACC group selecting from advantageous decks 54% compared with 59% for controls.

Within the EV model, the ACC and control groups did not significantly differ on the goodness-of-fit parameter (*F*(1, 64) = 9.35, *p* < .005, *η²* = 0.127), and a significant overall effect for trial block (*F* (1, 64) = 7.43, *p* < .01, *η²* = 0.104). The main effect of group was not significant (*F* (1, 64) = 0.18, NS). Post hoc comparisons revealed that the difference between performance on Blocks 1 and 2 was not significant in the participants with ACC (*t* = −0.37, *p* = .72), whereas the control group showed a significant improvement over the first two trial blocks (*t* = 3.50, *p* = .002). A similar group-by-block analysis of later test performance, involving blocks 3–5, yielded no significant differences (*p* > .30). By Block 5, ACC participants made advantageous choices 56% on average, comparable with 59% for controls.

Within the EV model, the ACC and control groups did not significantly differ on the goodness-of-fit parameter (*F*(1, 64) = 0.16, *p* = .69, *η²* = 0.003), indicating that the EV model worked just as well in describing the choice behavior of ACC participants as controls. However, group differences were evident on the three problem-solving parameters. The ACC group had a significantly greater average value on the motivation parameter (*F*(1, 64) = 4.75, *p* < .05, *η²* = 0.07) indicating that persons with ACC were more motivated by monetary losses than control participants (Fig. 2A). Furthermore, 48% of the ACC group (19 of the 40 participants) were motivated by losses only (i.e., had a score of 1 on the motivation parameter), compared with

| Table 1. Means (M) and standard deviations (SD) for ACC and control groups on demographic and IGT variables |

<table>
<thead>
<tr>
<th></th>
<th>ACC (n = 40)</th>
<th>Range</th>
<th>Control (n = 26)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>26.78 (11.51)</td>
<td>11–55</td>
<td>26.31 (9.38)</td>
<td>17–51</td>
</tr>
<tr>
<td>FSIQ</td>
<td>96.80 (13.54)</td>
<td>78–129</td>
<td>99.65 (7.62)</td>
<td>84–113</td>
</tr>
<tr>
<td>VIQ</td>
<td>98.23 (16.46)</td>
<td>76–140</td>
<td>99.54 (9.64)</td>
<td>84–125</td>
</tr>
<tr>
<td>PIQ</td>
<td>95.85 (14.16)</td>
<td>69–132</td>
<td>99.77 (8.98)</td>
<td>77–119</td>
</tr>
<tr>
<td>Overall IGT</td>
<td>−$258 (628)</td>
<td>−$1,600 to $1,500</td>
<td>−$90 (726)</td>
<td>−$1,250 to $1,850</td>
</tr>
<tr>
<td>Decision bias</td>
<td>6.28 (21.98)</td>
<td>−26–60</td>
<td>11.96 (23.27)</td>
<td>−32–60</td>
</tr>
<tr>
<td>Aver run length (log)</td>
<td>0.14 (0.18)</td>
<td>0.01–0.96</td>
<td>0.27 (0.24)</td>
<td>0.01–0.84</td>
</tr>
<tr>
<td>Longest run (log)</td>
<td>0.65 (0.34)</td>
<td>.30–1.46</td>
<td>0.89 (0.45)</td>
<td>3.0–1.56</td>
</tr>
<tr>
<td>EV model fit</td>
<td>7.34 (22.43)</td>
<td>−8.56 to 92.46</td>
<td>9.45 (18.05)</td>
<td>−11.85 to 51.56</td>
</tr>
<tr>
<td>Learning (recency)</td>
<td>0.44 (.43)</td>
<td>0–1</td>
<td>0.26 (.37)</td>
<td>0–1</td>
</tr>
<tr>
<td>Motivation (Attention to loss)</td>
<td>0.64 (.38)</td>
<td>0–1</td>
<td>0.44 (.32)</td>
<td>0–1</td>
</tr>
<tr>
<td>Consistency</td>
<td>−0.31 (3.17)</td>
<td>−5–5</td>
<td>1.24 (2.70)</td>
<td>−5–5</td>
</tr>
</tbody>
</table>

**Notes:** ACC = Agenesis of the corpus callosum; FSIQ = full-scale intelligence quotient; IGT = Iowa Gambling Task; EV = expectancy valence.
only 15% of the control group (4 of the 26 participants; $\chi^2 = 8.74, p < .005$). On the choice consistency parameter, the ACC group scored significantly below controls ($F(1, 64) = 4.18, p < .05, \eta^2_p = 0.06$), indicating that participants with ACC utilized a less consistent decision-making strategy (Fig. 2B). Finally, results from the learning (recency) parameter indicated that the ACC group was somewhat more influenced by recent trials than controls ($F(1, 64) = 2.93, p = .09, \eta^2_p = 0.04$) (Fig. 2C).

**Discussion**

Previous studies had suggested that individuals with ACC have a core difficulty in performing tasks that require complex novel problem-solving, whether in the social, behavioral, or cognitive domains (Brown & Paul, 2000; Gott & Saul, 1978; Paul et al., 2007; Sauerwein & Lassonde, 1994; Smith & Rourke, 1995; Solursh et al., 1965; Symington et al., 2010). The intent of this study was to better understand the nature of the problem-solving and decision-making impairments in individuals with ACC by utilizing a task that parallels the demands of real-life decisions involving consequence in the face of uncertainty (i.e., the IGT).

While individuals with ACC were not significantly different from matched controls in overall IGT performance (money lost or decision bias), they were slower in adjusting to the contingencies of the IGT over the first two 20-trial blocks, and they were also more likely to shift choices between decks (i.e., shorter run lengths). Results of the EV model indicated that individuals with ACC were markedly more attentive to losses, and less consistent and strategic in their choices, with a tendency to be more influenced by recent trials.

**Overall Gain/Loss and Decision-Bias Scores**

Generally, individuals with ACC were able to learn the contingencies of the task and eventually came to respond nearly as well as controls with respect to measures of overall IGT performance. They lost more money on average than controls, but this difference was not significant. By the last block of trials, they were selecting cards from the advantageous decks nearly as frequently as controls (56% vs. 59%). At this level of analysis, individuals with ACC were not deficient in their capacity to eventually comprehend task contingencies and make a majority of advantageous card-selection decisions.

However, analysis of the first two test blocks revealed delayed development of a winning decision bias in ACC. During the first block, the control group worked from the strategy of selecting from the big-payoff (disadvantageous) decks, but by block 2, they had made a major shift from selecting cards from the disadvantageous decks to a more advantageous selection strategy. In contrast, individuals with ACC on the average showed no bias either way during the entire first two blocks (Fig. 1). In other words, the participants with ACC were slower than the control participants at solving the selection
problem and learning the contingencies of the task, which is consistent with our hypothesis that ACC involves a core deficit in problem-solving in complex “novel” situations. During early trials, the task and its contingencies are most novel to participants in both groups, and the late development of an adequate decision bias in participants with ACC suggests a slower rate of understanding of the novel structure and contingencies of the task. The performance of individuals with ACC was also unusual with respect to significantly less tendency to settle on a single deck for long runs of choices (i.e., shorter average run length or longest run).

Since the IGT was originally developed to ascertain decision-making deficits in patients with localized damage to the prefrontal cortex, it is informative to compare the performance of people with ACC to those with frontal lobe dysfunction. The results of the current study showed that persons with ACC achieve similar overall results to control participants, in contrast to patients with frontal lobe disorder who perform markedly worse than controls. Although Bechara and colleagues (1994) originally implicated the VmPFC as the primary area of the frontal lobes affecting IGT performance, more recent research has demonstrated that persons with lesions in other brain areas may also perform significantly poorly on the IGT (Clark et al., 2003; Fellows & Farah, 2005; MacPherson et al., 2009; Maia & McClelland, 2004; Manes et al., 2002). The current results show that congenital callosal absence is not sufficient to markedly impact overall performance on the IGT. Although persons with ACC have difficulty in negotiating the complexities of social situations, this is not due to the sort of capricious decision-making associated with the social processing disorder in frontal lobe brain damage. While individuals with ACC were slower to solve the problem, and more likely to jump between decks, the contingencies of the task eventually came to control choice behavior.

Fig. 2. Box plots of the three EV parameters comparing individuals with ACC and controls.
Results of the EV Model

Although overall IGT performance was not markedly abnormal in our ACC sample, the application of the EV computational model to choice-by-choice decisions on the IGT indicated that the pattern of decision-making differed significantly between those with ACC and controls. Participants with ACC differed most significantly from controls on the motivation parameter, exhibiting greater attention to monetary losses. Nearly half (48%) of the ACC group were motivated entirely by losses (i.e., a score of 1.0 on the motivation parameter) compared with only 15% of controls. This result is consistent with the observation that during testing individuals with ACC tended to be overly cautious when assessing risk, often switching from decks immediately after they experienced a loss regardless of how many wins that deck had supplied (consistent also with their short run lengths). It is possible that persons with ACC adapted a loss-aversion strategy as a result of a history of difficulty with problem-solving in complex and novel situations. In which case, loss aversion may not reflect a specific cognitive deficit on the IGT so much as an adaptive behavioral habit. However, it is also possible that the nature of the IGT significantly taxed the problem-solving capacity of participants with ACC in a manner that elicited a simple loss-aversion strategy. Specifically, the varying reinforcements presented in the IGT involve uncertainty and a certain degree of somatic arousal. If participants with ACC had the predicted arousal, but lacked the problem-solving skills to apply the game-outcome and somatic information flexibly, they may have responded by selecting a strategy that simply reduces short-term anxiety (i.e., mere loss aversion). The absence of cognitive flexibility and greater use of rigid strategies and rules is commonly described by parents of individuals with ACC and is also a characteristic symptom of autism spectrum disorders.

Participants with ACC also had lower choice-consistency scores, suggesting that they form a less coherent and consistent strategy for selecting from different decks than control participants. While loss aversion is in some sense a strategy, it reflects decisions based on loss avoidance only, and not also on the degree to which gain might be expected from a choice. It is possible that, without the larger integrative cortical networks made possible by the corpus callosum, individuals with ACC do not readily integrate experience into a larger meta-representation of the task and its contingencies from which a strategy might emerge. In the absence of a consistently applied meta-representation of the task, their choices are more vulnerable to the influence of recent outcomes, particularly losses, as well as to lapses in attention. Aversion to loss, lack of a consistent pattern of choice, and a tendency to be influenced by recent trials were reflected also in a greater likelihood of the participants with ACC to switch decks, resulting in shorter runs of choices from the same deck.

Previous research has suggested different characteristic guessing strategies for the right and left hemispheres in split-brain patients during a two-option guessing task. According to Wolford, Miller, and Gazzaniga (2000), the left hemisphere looks for patterns of occurrence, and endeavors to match guesses to the past frequency of occurrences—a strategy that is characteristic of the performance of healthy controls. The right hemisphere, however, tends to maximize the probability of being correct by always guessing the most frequently occurring alternative. Thus, these authors concluded that the left hemisphere plays a major role in detecting patterns and forming hypotheses. To the degree that individuals with ACC tended not to adopt consistent selection strategies based on larger patterns of outcomes (i.e., significantly lower consistency), but to be driven primarily by losses, their IGT behavior might be characterized as a right hemisphere strategy.

Finally, while the ACC group did not significantly differ from the control group on the learning (recency) parameter, they tended to be more influenced by recent trials, that is, more rapid discounting of past outcomes. A high degree of loss sensitivity, as well as shorter runs of choosing from the same deck, would be consistent with rapid discounting of the outcomes of past trials and heavy reliance on recency. This would also be expected in individuals who are slow in comprehending overall game contingencies and forming a coherent game strategy.

Using the EV model, Yechiam and colleagues (2008) demonstrated that participants with orbital frontal lobe damage, as well as violent criminals (murder or assault) performed poorly due to their inconsistent decision-making pattern and inability to learn the contingencies of the task, leading to risky decision-making. In contrast, participants with ACC were not markedly deficient overall on the IGT, differing from control participants most markedly in the motivation behind their choices, that was heavily influenced by losses. Thus, the cognitive differences on the IGT observed between people with ACC and control participants were very different from that seen in disorders of the frontal lobe.

Patients with localized lesions to the right somatosensory and insular cortex (RSIC) exhibited a similar EV pattern to persons with ACC, including more inconsistent selections and greater loss aversion than controls (Yechiam et al., 2005). Although patients with RSIC lesions emitted normal autonomic responses to gains and losses, their subjective ratings of these experiences were markedly reduced. In other words, the somatic marker system was intact, but they were unable to apply that information successfully. A similar dissociation between arousal response and subjective rating was previously reported in individuals with ACC (Paul et al., 2006). Taken together, these findings suggest that while a single hemisphere may register emotional arousal, interpreting and ascribing meaning to that arousal (in this case related to a card selection) would involve integration of information from diverse, presumably bi-hemispheric cortical networks.
IGT Performance in ACC Versus AD

We noted earlier the behavioral similarities between individuals with ACC and individuals on the high-functioning end of the autism spectrum as rated by parents (Badaruddin et al., 2007). Data from the IGT also suggest similarity between persons in these two diagnostic categories. Johnson and colleagues (2006) found that individuals with AD were also able to perform normally with respect to overall IGT scores. The average rate of advantageous selections was the same for ACC (54%) and AD (54%), and, in both cases, the mean decision bias was slightly less than that of controls, but not significantly different.

Johnson and colleagues (2006) report a tendency of individuals with AD to switch more frequently than controls between decks (i.e., shorter run lengths) that was very similar to the shorter run lengths found in individuals with ACC in the current study. Using the \( r \)-values reported by Johnson and colleagues, the effect sizes with respect to controls for longest run were comparable in the two groups (ACC: \(-2.42\); ASD: \(-2.66\)). Johnson and colleagues commented that this striking feature of shorter run length had not previously been found in other disorders. Thus, ACC and AD are similarly unique with respect to significantly diminished run lengths for card choice in the IGT (at least as far as has been reported in the literature).

The EV outcomes in ACC are also very similar to the pattern found in studies of individuals with AD (Johnson et al., 2006). Both groups had relatively high values on the motivation parameter (ACC \( M = 0.65 \); AD \( M = 0.59 \)) and the effect size with respect to controls was similar (Cohen’s \( d = 0.569 \) and 0.589, respectively). In addition, 48% of the ACC group and 40% of the AD group had motivation parameter scores of 1. Thus, both groups tended to be highly averse to loss. Both groups were also significantly impaired on the choice-consistency parameter, with mean scores in the negative range (ACC, \( M = -0.32 \); AD, \( M = -0.74 \)), indicating that they made more erratic choices than controls. The more negative mean score in the AD group, as well as a greater effect size compared to controls (Cohen’s \( d = 0.536 \) for ACC vs. 0.783 for AD) suggests the possibility of greater deficiency in choice-consistency in persons with AD than participants with ACC. This outcome is consistent with the results of Badaruddin and colleagues (2007), such that children with high-functioning ASD displayed similar problems in attention, cognitive processes, and social interactions (as observed by parents), but these problems were rated as less severe in children with ACC than in those with autism.

Finally, on the IGT, neither group was significantly different from controls on the learning (recency) parameter, although there was a trend in the ACC group not seen in the AD study (Johnson et al., 2006). This trend in ACC is consistent with a fairly sizable difference between the parameter means for the ACC (\( M = 0.45 \)) and the AD (\( M = 0.09 \)) groups, as well as differences in effect size for this parameter (Cohen’s \( d = 0.449 \) and 0.300, respectively). Thus, it would seem that both groups make loss-averse and inconsistent choices, but persons with ACC do so based on somewhat greater impact of the outcome of recent trials.

It may be that similarity in IGT outcome between AD and ACC reflects abnormality of white matter development and cortical integration in both disorders. For example, Courchesne and Pierce (2005) reported results indicating that individuals with AD have excessive local connectivity (particularly in the frontal lobes), but diminished long distance connectivity (between frontal and posterior cortex). Individuals with AD also have diminished volume and functional anisotropy of the corpus callosum (Alexander et al., 2007; Kilian et al., 2008). Thus, similarity between ACC and AD in their reduced ability to develop a consistent IGT strategy and strong attention to loss may reflect a somewhat similar deficiency in white matter development and organization. Further research directly comparing these two clinical groups is needed to more confidently assert this similarity.

Summary and Limitations

ACC is a congenital disorder that, in some cases, is accompanied by other malformations of the brain. In most cases, other major malformations would result in structural abnormalities visible on MRI or below-normal FSIQ, both of which would cause individuals to be excluded from this research. However, cellular-level abnormalities that might more subtly affect cognition but are not visible in an MRI, might avoid our exclusionary criteria. For example, Kaufman and colleagues (2008) found reduced numbers of Von Economo neurons in the brains of two individuals with ACC when examined at autopsy. Thus, it cannot be entirely assured (or known given current technology) that no other neuropathology was consistently present in our ACC group. Thus, we cannot conclude that all of the deficits appearing in the ACC group were in fact entirely related to callosal absence alone and were not impacted by other unknown neuropathology shared in this population. Nevertheless, a major contribution of this study is a further description of the syndrome associated with ACC.

In this study, relatively high-functioning individuals with ACC showed normal overall performance on the IGT. However, they were slower in the development of an appropriate response bias. In addition, they demonstrated shorter run lengths, greater
attention to losses (the motivation parameter) and less consistent decision-making (the choice-consistency parameter). These outcomes demonstrate that individuals with ACC are overly cautious and averse to negative outcomes, as well as less strategic in decision-making than controls. In all, the outcome of the IGT is consistent with the hypothesis that individuals with ACC have deficits in problem-solving in the face of complexity and novelty, although on the IGT this tendency is manifest more in trial-by-trial response patterns than in final game outcome.

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Conflict of Interest

None declared.

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