Journal of the International Neuropsychological Society (2023), 1–9
doi:10.1017/S1355617723000218

Research Article

Inhibitory control in children with agenesis of the corpus callosum compared with typically developing children

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Abstract

Objectives: The developmental absence (agenesis) of the corpus callosum (AgCC) is a congenital brain malformation associated with risk for a range of neuropsychological difficulties. Inhibitory control outcomes, including interference control and response inhibition, in children with AgCC are unclear. This study examined interference control and response inhibition: 1) in children with AgCC compared with typically developing (TD) children, 2) in children with different anatomical features of AgCC (complete *vs.* partial, isolated *vs.* complex), and 3) associations with white matter volume and microstructure of the anterior (AC) and posterior commissures (PC) and any remnant corpus callosum (CC). **Methods:** Participants were 27 children with AgCC and 32 TD children 8–16 years who completed inhibitory control assessments and brain MRI to define AgCC anatomical features and measure white matter volume and microstructure. **Results:** The AgCC cohort had poorer performance and higher rates of below average performance on inhibitory control measures than TD children. Children with complex AgCC had poorer response inhibition performance than children with isolated AgCC. While not statistically significant, there were select medium to large effect sizes for better inhibitory control associated with greater volume and microstructure of the AC and PC, and with reduced volume and microstructure of the remnant CC in partial AgCC. **Conclusions:** This study provides evidence of inhibitory control difficulties in children with AgCC. While the sample was small, the study found preliminary evidence that the AC (f^2=.18) and PC (f^2=.30) may play a compensatory role for inhibitory control outcomes in the absence of the CC.

Keywords: inhibition; response inhibition; interference control; callosal agenesis; children; executive functions

(Received 27 July 2022; final revision 16 December 2022; accepted 23 January 2023)

Introduction

The corpus callosum (CC) is the largest white matter pathway and commissural tract in the brain, responsible for the transfer and integration of information across the left and the right hemispheres (Raybaud, 2010). Agenesis of the CC (AgCC) is one of the most common congenital brain malformations, with an estimated prevalence of at least 1:4000 live births (Glasset al., 2008). It can present as partial or complete absence of callosal fibers (Edwards et al. 2014), and as either an isolated malformation (albeit with commonly co-occurring anomalies including Probst bundles, colpocephaly and cingulate gyrus alteration) or as a complex condition with additional anomalies of the central nervous system (CNS) such as cortical malformations, hydrocephalus or interhemispheric cysts (Gupta & Lilford, 1995; Paul et al., 2007). AgCC can be associated with neurological symptoms such as epilepsy, and a large number of genetic syndromes (Edwards et al., 2014; Paul et al., 2007). Given the clinical heterogeneity associated with AgCC, general intellectual functioning and aspects of neuropsychological functioning in this population can range from normal to impaired (Paul et al., 2007; Siffredi et al., 2018).

In children with AgCC, one neuropsychological function of interest is inhibitory control, which is the ability to voluntarily inhibit irrelevant stimuli or responses, and is particularly important during childhood for academic achievement and social cognition/competencies (Latzman et al., 2010; Nigg, 2000; Nigg et al., 2006). Two main inhibitory processes can be distinguished: interference control and response inhibition (Friedman & Miyake, 2004; Munakata et al., 2011; Tiego et al., 2018). Interference control refers to the cognitive ability to resist environmental distractions and is commonly examined using tasks that involve competing relevant and irrelevant stimuli or stimulus dimensions, such as

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Cite this article: Soon E., Siffredi V., Anderson P.J., Anderson V.A., McIlroy A., Leventer R.J., Wood A.G., & Spencer-Smith M.M. Inhibitory control in children with agenesis of the corpus callosum compared with typically developing children. *Journal of the International Neuropsychological Society*, 1–9, https://doi.org/10.1017/S1355617723000218

Stroop tasks (Friedman & Miyake, 2004; Zhang et al., 1999). Conversely, response inhibition refers to the behavioral ability to suppress prepotent motor responses and is commonly examined using tasks that involve competing task-relevant responses and incorrect prepotent responses, such as go/no-go tasks (Chambers et al., 2009; Tiego et al., 2018). Inhibitory control processes have been found to rely on functional brain activations across the two hemispheres and to be dependent on interhemispheric communication (Cai & Leung, 2009; Schulte & Müller-Oehring, 2010), making AgCC a potential risk factor for difficulties in inhibitory control processes.

Few studies have explored select inhibitory control processes in individuals with AgCC. In a sample of older adolescents and adults ($n = 19$), difficulties in response inhibition was suggested by elevated errors of commission and detectability on a sustained attention task with medium effect sizes (Brown et al., 2020). Evidence of interference control difficulties has also been observed in children with AgCC ($n = 18$), with more errors on a Day/Night Stroop task than typically developing (TD) controls with a large effect size (Lábadi & Beke, 2017). Similar results were found in a study of children and adults with AgCC and IQ above 80 ($n = 36$), who demonstrated lower performance on timed measures on the Color-Word Interference Test compared to healthy controls with small to medium effect sizes (Marco et al., 2012). Together, these few studies suggest that individuals with AgCC might present with difficulties in inhibitory control processes, however no study has excamined both response inhibition and intereference control performance in children.

There is evidence that certain anatomical factors may influence neuropsychological functioning in individuals with AgCC. Children with isolated AgCC have been reported to perform better than those with complex AgCC on tasks of orienting and executive attention with large effect sizes, as well as in certain aspects of academic and executive functioning (Siffredi et al., 2018; Siffredi et al., 2019). Whether these findings are similar for children's inhibitory control processes is not known. There are mixed reports across studies as to the degree of influence callosal agenesis has on neuropsychological functioning. Marco et al. (2012) found no significant differences in response inhibition performance between partial and complete AgCC subgroups on the Color-Word Interference Test in a sample of children and adults ($n = 36$), although a test of trends indicated that the complete AgCC group had the poorest response inhibition performance, followed by those with partial AgCC and healthy controls. Other studies of children comparing partial and complete AgCC subgroups have also shown no significant differences in intellectual functioning and attention outcomes (Moutard et al., 2003; Moutard et al., 2012; Siffredi et al., 2019), but tests of trends were not conducted and few reported effect sizes making it difficult to conclude any meaningful trends.

In AgCC, plasticity mechanisms occurring in the atypically developing brain may allow for a certain degree of interhemispheric communication to occur (e.g., Mancuso et al., 2019; Siffredi et al., 2021). Any remnant of the CC in partial AgCC, as well as other important interhemispheric connections including the anterior (AC) and posterior (PC) commissures might be involved in neuroplastic compensatory mechanisms (Siffredi et al., 2019; Tovar-Moll et al., 2014; Siffredi et al., 2021). Tovar-Moll and colleagues (2014) reported that individuals with AgCC or CC hypoplasia (thinning of the CC) ($n = 6$) displayed atypical homotopic parietal bundles crossing the midline through the AC and the PC. Interestingly, an association with resting-state functional connectivity in parietal areas and the structural connectivity values of these atypical AC and PC pathways were reported. These results were partially replicated by Siffredi et al., (2021) in a cohort of children with AgCC ($n = 20$); the proposed atypical bundles were observed in only 30% of the children through the AC and 30% through the PC, and no evidence of an association between the observed atypical bundles and parietal functional connectivity was found. In a previous study in this cohort of children, Siffredi et al., (2019) explored the role of the AC and PC in attention processes in AgCC ($n = 21$) using volumetric and diffusion tensor measures of the AC and PC, including fractional anisotropy (FA), axial (AD) and radial (RD) diffusivity. Results suggested that microstructural properties of the AC and volume of the PC, moderated by the degree of CC agenesis (i.e., complete or partial AgCC), might play a role in select attentional processes. Thus, through developmental neuroplastic mechanisms, volume and microstructure of any remnant CC, the AC and PC may contribute to inhibitory control processes in children with AgCC.

The current study aimed to firstly examine inhibitory control processes (both interference control and response inhibition) in a cohort of children with AgCC compared with TD children aged 8-16 years. It was hypothesized that children with AgCC would have poorer performance on inhibitory control measures than TD children. Furthermore, it was expected that children with isolated AgCC would perform better than those with complex AgCC. It was unclear whether children with partial versus complete AgCC would differ in their performance on inhibitory control measures. The second aim of this study was to examine associations between white matter volume and microstructural properties (i.e., FA, AD, RD) of any remnant CC, the AC and PC with inhibitory control processes in children with AgCC. It was hypothesized that there would be positive associations between white matter volume and microstructural properties (i.e., higher mean FA, lower mean AD and mean RD) of any remnant CC, the AC and PC and performance on inhibitory control measures in children with AgCC.

Method

Participants

This study used data from the "Paediatric Agenesis of the Corpus Callosum Project" based at the Murdoch Children's Research Institute in Melbourne, Australia (Siffredi et al., 2018). A cohort of children with AgCC ($n = 28$) were recruited between September 2009 and February 2014 through radiology records at The Royal Children's Hospital (RCH) in Melbourne. Inclusion criteria were: 1) aged 8 years 0 months to 16 years 11 months, 2) magnetic resonance imaging (MRI) evidence of AgCC as part of routine clinical work-up, 3) English-speaking, and 4) the capacity to engage in neuropsychological testing. One child in the AgCC cohort was excluded based on new diffusion analysis (Siffredi et al., 2019; 2021) which identified participant 007 (Siffredi et al., 2018) had a dysmorphic CC as part of holoprosencephaly. This analysis did not identify any other children that should be excluded. Of the total children screened for inclusion, 25 (37%) were excluded due to severe cognitive and/or motor impairments, requiring assistance in daily living activities, and inability to engage in neuropsychological testing. A group of 32 TD children were recruited through advertisements in local schools and staff at the RCH. The TD group was comparable for age and sex to the AgCC group, English-speaking and had no history of a neurological or neurodevelopmental disorder.

https://doi.org/10.1017/S1355617723000218 Published online by Cambridge University Press

Structural brain MRI of the children in the TD group showed no incidental abnormalities that would require clinical referral. Children in both groups had normal or corrected-to-normal vision and hearing based on parent reports. For the current study, children were included if they completed assessments of inhibitory control processes (i.e., interference control and response inhibition) and brain MRI.

The research was completed in accordance with the Helsinki Declaration. Ethical approval was obtained from The RCH Human Research Ethics Committee. Informed written consent was obtained from caregivers and participants (if above 10 years). Assessments of inhibitory control processes and brain MRI were completed at The RCH and performed on the same day.

Measures

Interference control

Interference control was measured using the Color-Word Interference (CWI) subtest from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001). The timed inhibition trial was used in analysis. Participants were presented with a page showing names of colors (color-words) printed in incongruent ink-colors and were required to name each ink-color (not color-word) as quickly and accurately as possible. Completion time and number of errors were recorded and converted to scaled scores ($M = 10$, $SD = 3$), with higher scores indicating better performance. Below average was defined as scores at least 1 SD less than the mean (standardized scores <7) in order to identify children in the AgCC and TD groups who were at least mildly impaired in inhibitory control outcomes.

Response inhibition

Response inhibition was measured using the Walk Don't Walk subtest from the Test of Everyday Attention for Children (TEA-Ch; Manly et al., 1999). Participants were given an A4 page showing a series of 14-square paths and asked to listen to a recording of tones. If a "go" tone was played, they were instructed to take one step along the path by marking a square. When a "no-go" tone was played, they were required to refrain from marking a square. A total score reflected the number of paths correctly marked (range 0-20). Scaled scores ($M = 10$, $SD = 3$) were used, with higher scores reflecting better performance. Below average was defined as scores at least 1 SD less than the mean (standardized scores <7) in order to identify children in the AgCC and TD groups who were at least mildly impaired in inhibitory control outcomes.

Intelligence

Full-Scale IQ was estimated using the four-subtest version of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). For participants in the study who had recently completed clinical neuropsychological assessment, their Full-Scale IQ score from the Wechsler Intelligence Scale for Children – 4th Edition (WISC-IV; Wechsler, 2003) was used. The Full-Scale IQ scores of the WASI and WISC-IV have high concurrent validity (Saklofske et al., 2000). Age and sex standardized scores were used ($M = 100$, SD 15).

Neuroimaging

MRI acquisition

A mock scan was conducted first to familiarize the child with the scanning process. Brain MRI images were obtained using a 3T MAGNETOM Trio scanner with a 32-channel head coil, located at the RCH. T1 images were acquired using an MP-RAGE sequence (Magnetization Prepared Rapid Gradient Echo) with the following parameters: repetition time = 1900 msec, echo time = 2.71 msec, inversion time = 900 msec, flip angle = 9°, field of view = 256 mm, voxel size = .7 x .7 x .7 mm. The T1 MP-RAGE sequence was converted from native DICOM to NIFTI format using MRIcron (http://www.mccauslandcenter.sc.edu/mricro/mricron/) the quality of T1-weighted MR images for each participant were carefully inspected. Parameters used to acquire single-shell echo planar diffusion-weighted imaging (DWI) were: b-value = 3000 sec/mm^2, 50 gradient directions, repetition time = 8200 msec, axial slices = 2.3 mm, echo time = 112 msec, field of view = 240 mm, matrix size = 104*104*54, voxel size = 2.3 x 2.3 x 2.3 mm. One scan without diffusion weighting (b-factor = 0) was included as part of the single diffusion acquisition.

Anatomical features of AgCC

To determine the anatomical features of AgCC (complete or partial, isolated or complex), structural T1-weighted MR images were reviewed by a pediatric neurologist with expertise in brain malformations (RL) using a specially modified protocol to characterize AgCC and associated CNS anomalies (Anderson et al., 2009; Leventer et al., 1999). AgCC type was characterized as: (a) partial = absence of a section of the CC; or complete = absence of the entire CC; (b) isolated = absence of additional CNS anomalies (excluding commonly co-occurring anomalies, e.g., Probst bundles); or complex = presence of additional CNS anomalies.

Volumetric measures of AC and PC, and remnant CC in partial AgCC

A regions of interest (ROI) approach was used to manually define the AC, PC, and remnant CC (in partial AgCC) in native T1 space using MRIcron and MRview, and as described in Siffredi et al., (2019). Drawings were restricted to five slices in the sagittal axis, and unrestricted in axial and coronal axes. Two researchers conducted the drawings, where one was considered the reference drawer. Calculation of the number of voxels included in each drawing was conducted first, followed by calculation of the percentage of overlapping voxels between the two drawings. If there was more than 80% overlap, the ROIs of the reference drawing were used. If there was less than 80% overlap, the ROIs were redrawn by both researchers until there was 80% overlap. In the AgCC cohort, the mean overlap between the two drawers was 84.3% (SD=10.76, range 66.7 to 100%) for the AC, with it needing to be redrawn for 6 children because the 80% overlap was not reached, and 84.7% (SD=20.69, range 11.1 to 100%) for the PC, with it needing to be redrawn for 8 children because the 80% overlap was not reached. The final ROI used was the reference drawing. Measures of volume were calculated using the total number of voxels in the ROI as a ratio of whole-brain number of voxels. To adjust for differences in total brain volumes, volumes of the AC and PC as well as the remaining corpus callosum, were corrected as a ratio to total brain volume (ROI volume divided by representative brain volume; O'Brien et al., 2011). The Brain Extraction Tool (BET) from FSL was applied to the T1 image. Whole-brain volume was extracted by calculating the volume of the "brain extracted" T1 image.

Diffusion tensor measures of ROIs

DW-images were eddy current and motion corrected using the Eddy tool from the FSL package in order to minimize distortions due to eddy currents and to reduce simple head motion (Andersson & Sotiropoulos, 2016). MRtrix software was used to extract the b = 0 image from DW-images and brain-only images

https://doi.org/10.1017/S1355617723000218 Published online by Cambridge University Press

Table 1. Participant characteristics

	Agenesis of the corpus callosum (AgCC) group ($n = 27$)	Typically developing (TD) group ($n = 32$)	p-Value
Age in years, Mean (SD)	12.09 (2.51)	11.99 (2.41)	.88
Male sex, n (%)	17 (63.0)	16 (53.3)	.32
Non-right-handed[a], n (%)	13 (48.2)	3 (9.4)	<.001
Anatomical features of AgCC, n (%)			
Complete; Partial	14 (51.9); 13 (48.2)	–	–
Isolated; Complex	11 (40.7); 16 (59.3)	–	–
Associated conditions, n (%)			
Seizure disorder diagnosed	5 (18.5)		
Genetic condition diagnosed	4 (14.8)		
Full-scale IQ[b], Mean (SD)	78.07 (17.30)	112.66 (11.16)	<.001
Full-scale IQ[b] <70, n (%)	5 (18.52)	–	
Social risk[c], Mean (SD)	2.70 (2.25)	1.13 (1.47)	.002

[a]Handedness was estimated using the Edinburgh Handedness Inventory (Groen et al., 2012; Oldfield, 1971). Non-right-handed = −40 to −100 (left-handed) and −40 to +40 (mix-handed).
[b]Full-scale IQ was measured using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) or the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV; Wechsler, 2003).
[c]Social risk was estimated by the Social Risk Index (Roberts et al., 2008), a composite score based on family structure, education of primary caregiver, occupation and employment status of primary income earner, language spoken at home and maternal age at birth. The score ranges from 0–12, with a higher score indicating higher socio-economic risk.

were extracted using the Brain Extraction Tool (BET2) compiled in FSL (Jenkinson et al., 2005; Smith, 2002). Diffusion tensor maps (i.e., FA, AD $\lambda\| = \lambda1$, and RD $\lambda^{\perp} = (\lambda2 + \lambda3)/2$) were then extracted using MRtrix software and co-registered to the T1 image (Smith et al., 2006; Smith et al., 2007). The ROI images in T1 space were then used to extract tensor measures from the FA, AD, RD image transformed to T1 space: mean FA, mean AD, and mean RD.

Statistical analyses

To address hypothesis one, group differences (AgCC *vs.* TD) in inhibitory control mean scores were tested using linear regressions. Sensitivity analyses excluding children with IQ < 70 (i.e., 2 standard deviations, SD, below the mean) were performed to determine whether inhibitory control difficulties are beyond IQ impairment. Group differences (AgCC *vs.* TD) in rates of below average performance for each inhibitory control score were examined using logistic regressions, and subgroup differences in inhibitory control mean performance scores for the isolated versus complex AgCC subgroups as well as and the partial versus complete AgCC subgroups were examined in a series of linear regressions. To address hypothesis two, linear regressions examined potential associations between inhibitory control means scores and white matter volume and microstructure measures (i.e., mean FA, mean AD, and mean RD) of the AC, PC and any remnant CC in the AgCC group.

For all linear regressions, regression coefficients, 95% confidence intervals (CI), p-values and effect sizes (Cohen's f^2) were reported. Effect sizes were interpreted as: small effect ≥ 0.02, medium effect ≥ 0.15, large effect ≥ 0.35 (Cohen, 1988). To adjust for type 1 error, a Bonferroni correction was applied for analyses with multiple comparisons. For hypothesis one (AgCC *vs.* TD groups, isolated *vs.* complex AgCC subgroups, and partial *vs.* complete AgCC subgroups), an α-value of .02 (.05/3) was used. For hypothesis 2 an α-value of .004 (.05/12) was used. For all logistic regressions, odds ratios, 95% CIs and p-values were reported.

Results

Sample characteristics

Participants were 27 children with AgCC and 32 TD children aged 8-16 years (Table 1). In the AgCC cohort, there were roughly equal number of children with complete and partial AgCC, slightly more children had complex compared with isolated AgCC, and small numbers of children had a diagnosed seizure disorder and/or a genetic condition. The AgCC and TD groups were comparable in age and comprised similar proportions of males and females. The AgCC cohort had a lower mean IQ (in the Borderline range: mean 78.07, SD 17.30) than the TD group (in the Average range: mean 112.66, SD 11.16) ($t(57) = -34.58$, $p < .001$), and had a higher mean social risk compared with the TD group. Consistent with previous studies (e.g., Lábadi & Beke, 2017; Sauerwein & Lassonde, 1994), there were more non-right-handed children in our AgCC cohort compared to the TD group. With regard to the anatomical features of the AgCC cohort, there was a similar proportion of children with partial and complete AgCC, and there were slightly more children with complex compared with isolated AgCC.

Six participants with AgCC did not complete the diffusion-weighted MRI sequences. After quality checking of the anatomical T1 and diffusion-weighted MR images, an additional AgCC participant was excluded due to difficulties characterizing the corpus callosum malformation. The final sample for aim two of the current study comprised 20 children with AgCC.

Inhibitory control

The AgCC group performed significantly poorer than the TD group on all measures of inhibitory control (CWI completion time, CWI errors, Walk Don't Walk) with medium to large effect sizes (Table 2), with reduced spread and lower median scores in the AgCC group. Furthermore, children with AgCC had significantly higher odds than TD children of having below average performance on the inhibitory control measures. Results were similar after Bonferroni correction and in the sensitivity analysis excluding 5 children with IQ < 70 (Table 2).

Inhibitory control and anatomical features

For children with complete and partial AgCC, performance was comparable on all measures of inhibitory control (CWI completion time, CWI errors, and Walk Don't Walk), with small effect sizes (Table 3). While children with isolated and complex AgCC performed similarly on CWI completion time and errors with negligible effect sizes, those with isolated AgCC performed better on Walk Don't Walk with a medium effect size (Table 3). Results were similar after Bonferroni correction and in sensitivity analyses

https://doi.org/10.1017/S1355617723000218 Published online by Cambridge University Press

Table 2. Inhibitory control outcomes across agenesis of the corpus callosum (AgCC) and typically developing (TD) groups

	AgCC		TD		AgCC *vs*. TD					Sensitivity Analysis Excluding Children with IQ <70		
	Mean (SD)	Below Ave Rate[a] *n* (%)	Mean (SD)	Below Ave Rate[a] *n* (%)	Below Ave Rate[a] Odds Ratio [95% CI]	*p*-value	Group Difference B [95% CI]	*p*-value	Effect Size	Group Difference B [95% CI]	*p*-value	Effect Size
CWIT completion time	7.00 (3.80)	12 (44.4%)	10.94 (2.09)	1 (3.1%)	24.8 [2.94, 208.92]*	.003	−3.94 [−5.51, −2.37]*	<.001	0.44	−3.53 [−5.11, −1.95]*	<.001	0.39
CWIT error	5.67 (4.20)	14 (51.9%)	9.88 (2.88)	2 (7.4%)	16.15 [3.20, 81.48]*	.001	−4.21 [−6.06, −2.35]*	<.001	0.36	−3.69 [−5.60, −1.79]*	<.001	0.29
Walk Don't Walk	4.64 (3.58)	18 (66.7%)	8.42 (3.30)	6 (18.8%)	10.71 [3.08, 37.30]*	<.001	−3.78 [−5.63, −1.93]*	<.001	0.31	−3.77 [−5.71, −1.83]*	<.001	0.31

Note. CWIT = Color-Word Interference Test. Standard scores were used for CWIT and Walk Don't Walk subtests. Effect sizes were measured using Cohen's f^2; small effect ≥ 0.02, medium effect ≥ 0.15, large effect ≥ 0.35 (Cohen, 1988).
[a]Below Average was defined as scores at least 1 SD less than the test mean (scores <7).
*Significance remained after applying the Bonferonni correction.

Table 3. Group comparisons in inhibitory control outcomes for complete and partial agenesis of the corpus callosum (AgCC) subgroups, and isolated and complex AgCC subgroups

	Complete *vs*. Partial AgCC			Sensitivity Analysis Excluding Children with IQ <70			Isolated *vs*. Complex AgCC			Sensitivity Analysis Excluding Children with IQ <70		
	Group Difference B [95% CI]	*p*-value	Effect Size	Group Difference B [95% CI]	*p*-value	Effect Size	Group Difference B [95% CI]	*p*-value	Effect Size	Group Difference B [95% CI]	*p*-value	Effect Size
CWIT completion time	0.74 [−2.32, 3.80]	.62	.01	1.00 [−2.32, 4.32]	.54	.02	0.46 [−2.66, 3.58]	.76	.004	−0.13 [−3.53, 3.28]	.94	<.001
CWIT error	0.25 [−3.15, 3.64]	.88	.001	−0.37 [−4.10, 3.37]	.84	.002	0.56 [−2.88, 4.01]	.74	.005	−0.31 [−4.12, 3.49]	.87	.001
Walk Don't Walk	1.23 [−1.75, 4.21]	.40	.03	0.10 [−3.23, 3.43]	.95	<.001	3.43 [0.72, 6.14]*	.015	.30	4.13 [1.40, 6.85]*	.005	.56

Note. CWIT = Color-Word Interference Test. Standard scores were used for CWIT and Walk Don't Walk subtests. Effect sizes were measured using Cohen's f^2; small effect ≥ 0.02, medium effect ≥ 0.15, large effect ≥ 0.35 (Cohen, 1988).
*Significance remained after applying the Bonferonni correction.

Table 4. Mean volume, fractional anisotropy (FA), axial diffusivity (AD) and radial diffusivity (RD) of remnant corpus callosum (CC), anterior commissure (AC) and posterior commissure (PC), and correlations with inhibitory control outcomes in children with agenesis of the CC (AgCC)

		CWIT completion time			CWIT error			Walk Don't Walk		
	Mean (SD)	β	*p*-value	Effect Size	β	*p*-value	Effect Size	β	*p*-value	Effect Size
AC ($n = 20$)										
Volume	0.00001 (0.000008)	0.18	.46	.03	−0.11	.65	.01	0.18	.48	.03
FA	0.15 (0.06)	0.12	.64	.01	−0.07	.78	.001	0.03	.92	.001
AD	0.001 (0.0001)	0.28	.24	.09	−0.19	.44	.04	−0.18	.48	.03
RD	0.001 (0.0002)	0.21	.39	.05	−0.39	.096	.18	−0.05	.84	.002
PC ($n = 20$)										
Volume	0.000004 (0.000001)	0.48	.038	.30	0.07	.79	.004	0.13	.61	.02
FA	0.10 (0.02)	0.10	.68	.01	−0.15	.52	.03	−0.21	.39	.05
AD	0.001 (0.00008)	−0.24	.31	.06	0.14	.57	.02	0.24	.33	.06
RD	0.001 (0.00008)	−0.04	.87	.002	−0.13	.57	.02	0.21	.40	.05
CC remnant ($n = 7$)										
Volume	0.0002 (0.0002)	−0.70	.080	.96	−0.24	.60	.06	−0.69	.085	.92
FA	0.34 (0.09)	−0.43	.34	.22	0.10	.84	.01	−0.27	.56	.08
AD	0.001 (0.00009)	0.31	.50	.11	0.06	.89	.004	−0.01	.98	.001
RD	0.0007 (0.0002)	0.25	.58	.07	−0.21	.65	.05	0.20	.67	.04

Note. CWIT = Color-Word Interference Test. Standard scores were used for CWIT and Walk Don't Walk subtests. Effect sizes were measured using Cohen's f^2; small effect ≥ 0.02, medium effect ≥ 0.15, large effect ≥ 0.35 (Cohen, 1988).

excluding 5 children with IQ < 70 ($n = 2$ complete and $n = 3$ partial; $n = 3$ isolated and $n = 2$ complex) (Table 2).

Inhibitory control and volumetric and microstructural properties of the AC, PC, and any remnant CC

For the AC, RD was negatively associated with CWI error scores with a medium effect size, however this association was not statistically significant (Table 4). For the PC, volume was positively associated with CWI completion time with a medium effect size, but did not remain after Bonferroni correction. All other associations between volume and microstructural properties and performance on the inhibitory control measures in our cohort of children with AgCC were non-significant with negligible effect sizes.

In children with partial AgCC, volume of the remnant CC was negatively associated with performance on two of the three inhibitory control measures (CWI completion time and Walk Don't Walk measures) with large effect sizes, and FA was negatively associated with one of the measures (CWI completion time) with a medium effect size, but these patterns of associations were non-significant. All other associations between volume and microstructure of the remnant CC and performance on the inhibitory control measures were non-significant with negligible effect sizes (Table 4).

Results were similar in sensitivity analyses excluding children with IQ <70 ($n = 0$ to 4), results not shown.

Discussion

This study found that both interference control and response inhibition processes are poorer in children with AgCC compared with TD children. We found little evidence that the anatomical features of AgCC (i.e., complete *vs*. partial, isolated *vs*. complex) were associated with select inhibitory control processes, although children with complex AgCC showed poorer response inhibition compared to children with isolated AgCC. Our findings contribute preliminary evidence (based on effect sizes in the absence of statistical significance) for associations between structural properties of the AC and PC with inhibitory control processes in children with AgCC.

Our AgCC cohort exhibited poorer performance and higher rates of below average performance in inhibitory control processes compared with TD children. This is consistent with the limited studies that have examined inhibitory control in individuals with AgCC, where evidence of difficulties in interference control or response inhibition have been found in small samples of children and samples consisting of both children and adults (Brown et al., 2020; Lábadi & Beke, 2017; Marco et al., 2012). Below average performance in both interference control and response inhibition process may have important implications for the academic functioning of children with AgCC. For example, during childhood and adolescence, poor response inhibition may be a marker of emerging arithmatic skills (Gray & Reeve, 2014), and interference control has also been found to predict mathematical achievement and reading comprehension (Kieffer et al., 2013; Latzman et al., 2010). It is important to note that although we found higher rates of below average performance in children with AgCC compared with TD children, not all children with AgCC in our cohort experienced inhibitory control difficulties, with rates ranging from 44.4-66.7% across interference control and response inhibition measures. This further highlights the heterogeneity of neuropsychological outcomes that have been associated with AgCC (Paul et al., 2007; Siffredi et al., 2018).

Our findings suggest that one source of the heterogeneity associated with inhbiitory control outcomes for children with AgCC is whether it presents as an isolated or complex condition. In examining some of the key anatomical features of AgCC, children with isolated AgCC were found to have better response inhibition than those with complex AgCC. This is consistent with our previous studies of this cohort of children with AgCC that have found better outcomes in certain aspects of attention, academic, and executive functioning in those with isolated compared with complex AgCC (Siffredi et al., 2018; Siffredi et al., 2019). It is also in line with studies by others of individuals diagnosed with AgCC prenatally showing better neurodevelopmental outcomes for those with isolated compared with complex conditions (Francesco et al., 2006; Fratelli et al., 2007). It is possible that the presence of additional anomalies of the CNS in individuals with complex AgCC may increase difficulties and lead to poorer outcomes. Together, these findings may help to explain why not all children with AgCC in our cohort experienced inhibitory control difficulties.

We found preliminary evidence that select altered volume and microstructure of the AC, PC and remnant CC in children with AgCC are associated with select inhibitory control processes,

https://doi.org/10.1017/S1355617723000218 Published online by Cambridge University Press

contributing to the discussion of the potential role of alternative interhemispheric pathways for cognitive compensation. Although we found no statistically significant associations in our cohort, perhaps due to the small sample sizes of our subgroups ($n = 7$ to 20), we did find medium to large effect sizes for select associations (4 of the 36 associations tested) that may suggest evidence of altered volume and microstructure of the AC, PC, and remnant CC in children with AgCC. With respect to the AC ($n = 20$), a medium effect size was found for the association between better interference control and lower RD. This could reflect differences in myelin integrity and production, where children with better interference control may exhibit increased myelin integrity and production in the AC (Kumar et al., 2008; Song et al., 2005). Furthermore, this study also found a medium effect size for the association between better interference control and greater volume of the PC ($n = 20$). Previous studies of individuals with AgCC have reported atypical parietal bundles in the PC (Siffredi et al., 2021; Tovar-Moll et al., 2014). Moreover, Siffredi et al. (2019) found a positive association between volume of the PC and orienting attention in children with AgCC. In line with these findings, greater volume of the PC along with increased parietal connections may allow for better interference control functioning.

In the case of partial AgCC ($n = 7$), the volume and FA of the remnant CC showed associations with interference control and response inhibition outcomes that were of medium and large effect size respectively. Although we had expected positive associations, the observed negative associations between white matter volume and microstructure of any remnant CC and inhibitory control may reflect a difference in neuroplastic responses. It is possible that more disruption to the development of the CC allows for a more efficient neuroplastic response in alternative pathways like the AC and PC, and therefore leads to better cognitive functioning.

This study had several strengths. By examining white matter volume and microstructure of the AC, PC, and remnant CC, this study went beyond examining outcomes, to start to understand the mechanisms behind both aspects of inhibitory control processes in children with AgCC. Our cohort is representative of children with AgCC who present for clinical attention. While it is acknowledged that one of the inclusion criteria for the cohort was the capacity to engage in cognitive testing, this study did not have a strict selection criterion for IQ (e.g., IQ > 80) that has been used in previous research examining AgCC. Thus, findings from this study may be better able to represent inhibitory control outcomes in all children presenting for clinical attention, including those who may have lower intellectual functioning. Although subgroup analyses may have lacked sufficient power to detect significant associations, our cohort of children with AgCC ($n = 27$) can be considered large in comparison to previous studies (e.g., Brown et al., 2020, $n = 17$; Lábadi & Beke, 2017, $n = 18$; Tovar-Moll et al., 2014, $n = 6$), and medium to large effect sizes that were found may suggest clinically meaningful associations. Future research with sufficiently large samples will be required to replicate our findings, which could be achieved through multisite collaborations. While our findings indicate that children with a combination of complex and partial AgCC are at risk for poor inhibitory control outcomes compared to children with other combinations of anatomical AgCC features, the interaction effects of overlapping neurological features were not examined due to the small numbers. Future studies with larger samples are required to test this hypothesis.

Conclusion

Our study demonstrated that children with AgCC are at risk for inhibitory control difficulties in interference control and response inhibition processes. We found inhibitory control functioning was similar for children with complete and partial AgCC, and while children with isolated and complex AgCC had similar interference control, response inhibition was poorer in complex compared with isolated AgCC. Our findings provide preliminary evidence that the AC and PC may play a compensatory role for inhibitory control processes in children with AgCC.

The results have important theoretical and clinical implications. By using a quantitative assessment of white matter volume and microstructure of the AC, PC, and any remnant CC, the findings provide insight into how the brain might respond to early callosal disruptions by using compensatory mechanisms through alternative pathways. This hypothesis has broader implications for our understanding of neuroplasticity during early development and its relationship with behavior and cognition in children with other congenital brain malformations. Furthermore, findings of this study suggest that individuals with AgCC may require clinical attention. Our findings may help clinicians to better determine prognostic outcomes for children with AgCC based upon their imaging features and could ultimately aid families with decisions regarding education or treatment options for their child.

While future research with larger samples is needed to replicate findings, the results provide new insight into inhibitory control functioning in children with AgCC and progresses our understanding of the heterogeneity in neuropsychological outcomes that is inherent to this common brain malformation.

Acknowledgments. We gratefully acknowledge the families who participated in this study and Kate Pope for her assistance in recruitment of the families.

Funding statement. This work was supported by the Boninchi Foundation from the University of Geneva; Victorian Government's Operational Infrastructure Support Program; and the Murdoch Children's Research Institute. Associate Professor Richard Leventer is supported by a Melbourne Children's Clinician Scientist Fellowship. Professor Vicki A. Anderson was supported by an Australian National Health and Medical Research Council (NHMRC) Senior Practitioner Fellowship. Professor Peter J. Anderson was supported by an NHMRC Leadership Fellowship (APP1176077).

Conflicts of interest. The authors report no conflicts of interest.

References

Anderson, V., Spencer-Smith, M., Leventer, R., Coleman, L., Anderson, P., Williams, J., Greenham, M., & Jacobs, R. (2009). Childhood brain insult: Can age at insult help us predict outcome? *Brain*, *132*, 45–56. https://doi.org/10.1093/brain/awn293

Andersson, J. L. R., & Sotiropoulos, S. N. (2016). An integrated approach to correction for off-resonance effects and subject movement in diffusion MR imaging. *Neuroimage*, *125*, 1063–1078. https://doi.org/10.1016/j.neuroimage.2015.10.019

Brown, W. S., Panos, A., & Paul, L. (2020). Attention, impulsivity, and vigilance in agenesis of the corpus callosum. *Neuropsychology*, *34*, 744–749. https://doi.org/10.1037/neu0000685

Cai, W., & Leung, H. C. (2009). Cortical activity during manual response inhibition guided by color and orientation cues. *Brain Research*, *1261*, 20–28. https://doi.org/10.1016/j.brainres.2008.12.073

Chambers, C. D., Garavan, H., & Bellgrove, M. A. (2009). Insights into the neural basis of response inhibition from cognitive and clinical neuroscience. *Neuroscience & Biobehavioral Reviews*, *33*, 631–646. https://doi.org/10.1016/j.neubiorev.2008.08.016

Cohen, J. E. (1988). *Statistical power analysis for behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (DKEFS)*. The Psychological Corporation.

Glass, H. C., Shaw, G. M., Ma, C., & Sherr, E. H. (2008). Agenesis of the corpus callosum in California 1983-2003: A population-based study. *American Journal of Medical Genetics, Part A*, *146A*, 2495–2500. https://doi.org/10.1002/ajmg.a.32418

Gray, S. A., & Reeve, R. A. (2014). Preschoolers' dot enumeration abilities are markers of their arithmetic competence. *PLoS ONE*, *9*(4), e94428. https://doi.org/10.1371/journal.pone.0094428

Groen, M. A., Whitehouse, A. J., Badcock, N. A., & Bishop, D. V. (2012). Does cerebral lateralization develop? A study using functional transcranial Doppler ultrasound assessing lateralization for language production and visuospatial memory. *Brain and Behavior*, *2*(3), 256–269. https://doi.org/10.1002/brb3.56

Gupta, J. K., & Lilford, R. J. (1995). Assessment and management of fetal agenesis of the corpus callosum. *Prenatal Diagnosis*, *15*, 301–312. https://doi.org/10.1002/pd.1970150402

Edwards, T. J., Sherr, E. H., Barkovich, J., & Richards, L. J. (2014). Clinical, genetic and imaging findings identify new causes for corpus callosum development syndromes. *Brain*, *137*, 1579–1613. https://doi.org/10.1093/brain/awt358

Francesco, P., Maria-Edgarda, B., Giovanni, P., Dandolo, G., & Giulio, B. (2006). Prenatal diagnosis of agenesis of corpus callosum: What is the neurodevelopmental outcome? *Pediatrics International*, *48*, 298–304. https://doi.org/10.1111/j.1442-200X.2006.02208.x

Fratelli, N., Papageorghiou, A. T., Prefumo, F., Bakalis, S., Homfray, T., & Thilaganathan, B. (2007). Outcome of prenatally diagnosed agenesis of the corpus callosum. *Prenatal Diagnosis*, *27*, 512–517. https://doi.org/10.1002/pd.1719

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology*, *133*, 101–135. https://doi.org/10.1037/0096-3445.133.1.101

Jenkinson, M., Pechaud, M., & Smith, S. (2005). BET2: MR-based estimation of brain, skull and scalp surfaces. Proceedings of the Eleventh Annual Meeting of the Organization for Human Brain Mapping, Toronto, ON, Canada, p. 167.

Kieffer, M. J., Vukovic, R. K., & Berry, D. (2013). Roles of attention shifting and inhibitory control in fourth-grade reading comprehension. *Reading Research Quarterly*, *48*, 333–348. https://doi.org/10.1002/rrq.54

Kumar, R., Macey, P. M., Woo, M. A., Alger, J. R., & Harper, R. M. (2008). Diffusion tensor imaging demonstrates brainstem and cerebellar abnormalities in congenital central hypoventilation syndrome. *Pediatric Research*, *64*, 275–280. https://doi.org/10.1203/PDR.0b013e31817da10a

Lábadi, B., & Beke, A. M. (2017). Mental state understanding in children with agenesis of the corpus callosum. *Frontiers in Psychology*, *8*, 94. https://doi.org/10.3389/fpsyg.2017.00094

Latzman, R. D., Elkovitch, N., Young, J., & Clark, L. A. (2010). The contribution of executive functioning to academic achievement among male adolescents. *Journal of Clinical and Experimental Neuropsychology*, *32*, 455–462. https://doi.org/10.1080/13803390903164363

Leventer, R. J., Phelan, E. M., Coleman, L. T., Kean, M. J., Jackson, G. D., & Harvey, A. S. (1999). Clinical and imaging features of cortical malformations in childhood. *Neurology*, *53*, 715–722. https://doi.org/10.1212/WNL.53.4.715

Marco, E. J., Harrell, K. M., Brown, W. S., Hill, S. S., Jeremy, R. J., Kramer, J. H., Sherr, E. H., & Paul, L. K. (2012). Processing speed delays contribute to executive function deficits in individuals with agenesis of the corpus callosum. *Journal of the International Neuropsychological Society*, *18*, 521–529. https://doi.org/10.1017/S1355617712000045

Mancuso, L., Uddin, L. Q., Nani, A., Costa, T., & Cauda, F. (2019). Brain functional connectivity in individuals with callosotomy and agenesis of the corpus callosum: A systematic review. *Neuroscience & Biobehavioral Reviews*, *105*, 231–248. https://doi.org/10.1016/j.neubiorev.2019.07.004

Manly, T., Robertson, I., Anderson, V., & Nimmo-Smith, I. (1999). *The Test of Everyday Attention for Children (TEA-Ch)*. Thames Valley Test Company.

Moutard, M. L., Kieffer, V., Feingold, J., Kieffer, F., Lewin, F., Adamsbaum, C., Gélot, A., Campistol I Plana, J., van Bogaert, P., André, M., & Ponsot, G. (2003). Agenesis of corpus callosum: Prenatal diagnosis and prognosis. *Child's Nervous System*, *19*, 471–476. https://doi.org/10.1007/s00381-003-0781-6

Moutard, M. L., Kieffer, V., Feingold, J., Lewin, F., Baron, J. M., Adamsbaum, C., Gélot, A., Isapof, A., Kieffer, F., & de Villemeur, T. B. (2012). Isolated corpus callosum agenesis: A ten-year follow-up after prenatal diagnosis (How are the children without corpus callosum at 10 years of age?). *Prenatal Diagnosis*, *32*, 277–283. https://doi.org/10.1002/pd.3824

Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O'Reilly, R. C. (2011). A unified framework for inhibitory control. *Trends in Cognitive Sciences*, *15*, 453–459. https://doi.org/10.1016/j.tics.2011.07.011

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, *126*(2), 220–246. https://doi.org/10.1037/0033-2909.126.2.220

Nigg, J. T., Wong, M. M., Martel, M. M., Jester, J. M., Puttler, L. I., Glass, J. M., Adams, K. M., Fitzgerald, H. E., & Zucker, R. A. (2006). Poor response inhibition as a predictor of problem drinking and illicit drug use in adolescents at risk for alcoholism and other substance use disorders. *Journal of the American Academy of Child & Adolescent Psychiatry*, *45*, 468–475. https://doi.org/10.1097/01.chi.0000199028.76452.a9

O'Brien, L. M., Zieger, D. A., Deutsch, C. K., Frazier, J. A., Herbert, M. R., Locascio, J. J. (2011). Statistical adjustments for brain size in volumetric neuroimaging studies: Some practical implications in methods. *Psychiatry Research: Neuroimaging*, *193*, 113–122. https://doi.org/10.1016/j.pscychresns.2011.01.007

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Paul, L. K., Brown, W. S., Adolphs, R., Tyszka, J. M., Richards, L. J., Mukherjee, P., & Sherr, E. H. (2007). Agenesis of the corpus callosum: Genetic, developmental and functional aspects of connectivity. *Nature Reviews Neuroscience*, *8*, 287–299. https://doi.org/10.1038/nrn2107

Raybaud, C. (2010). The corpus callosum, the other great forebrain commissures, and the septum pellucidum: Anatomy, development, and malformation. *Neuroradiology*, *52*, 447–477. https://doi.org/10.1007/s00234-010-0696-3

Roberts, G., Howard, K., Spittle, A. J., Brown, N. C., Anderson, P. J., & Doyle, L. W. (2008). Rates of early intervention services in very preterm children with developmental disabilities at age 2 years. *Journal of Paediatrics and Child Health*, *44*, 276–280. https://doi.org/10.1111/j.1440-1754.2007.01251.x

Saklofske, D. H., Caravan, G., & Schwartz, C. (2000). Concurrent validity of the Wechsler Abbreviated Scale of Intelligence (WASI) with a sample of Canadian children. *Canadian Journal of School Psychology*, *16*, 87–94. https://doi.org/10.1177/082957350001600106

Sauerwein, H. C., & Lassonde, M. (1994). Cognitive and sensori-motor functioning in the absence of the corpus callosum: Neuropsychological studies in callosal agenesis and callosotomized patients. *Behavioural Brain Research*, *64*, 229–240. https://doi.org/10.1016/0166-4328(94)90135-x

Schulte, T., & Müller-Oehring, E. M. (2010). Contribution of callosal connections to the interhemispheric integration of visuomotor and cognitive processes. *Neuropsychology Review*, *20*, 174–190. https://doi.org/10.1007/s11065-010-9130-1

Siffredi, V., Anderson, V., McIlroy, A., Wood, A. G., Leventer, R. J., & Spencer-Smith, M. M. (2018). A neuropsychological profile for agenesis of the corpus callosum? Cognitive, academic, executive, social, and behavioral functioning in school-age children. *Journal of the International Neuropsychological Society*, *24*, 445–455. https://doi.org/10.1017/S1355617717001357

Siffredi, V., Wood, A. G., Leventer, R. J., Vaessen, M., McIlroy, A., Anderson, V., . . . Spencer-Smith, M. M. (2019). Anterior and posterior commissures in agenesis of the corpus callosum: Alternative pathways for attention processes? *Cortex*, *121*, 454–467. https://doi.org/10.1016/j.cortex.2019.09.014

Siffredi, V., Preti, M. G., Kebets, V., Obertino, S., Leventer, R. J., McIlroy, A., Wood, A. G., Anderson, V., Spencer-Smith, M. M., & Van De Ville, D.

https://doi.org/10.1017/S1355617723000218 Published online by Cambridge University Press

(2021). Structural neuroplastic responses preserve functional connectivity and neurobehavioural outcomes in children born without corpus callosum. *Cerebral Cortex*, *31*, 1227–1239. https://doi.org/10.1093/cercor/bhaa289

Smith, S. M. (2002). Fast robust automated brain extraction. *Human Brain Mapping*, *17*, 143–155. https://doi.org/10.1002/hbm.10062

Smith, S. M., Jenkinson, M., Johansen-Berg, H., Rueckert, D., Nichols, T. E., Mackay, C. E., Watkins, K. E., Ciccarelli, O., Cader, M. Z., Matthews, P. M., & Behrens, T. E. (2006). Tract-based spatial statistics: Voxelwise analysis of multi-subject diffusion data. *Neuroimage*, *31*, 1487–1505. https://doi.org/10.1016/j.neuroimage.2006.02.024

Smith, S. M., Johansen-Berg, H., Jenkinson, M., Rueckert, D., Nichols, T. E., Miller, K. L., Robson, M. D., Jones, D. K., Klein, J. C., Bartsch, A. J., & Behrens, T. E. (2007). Acquisition and voxelwise analysis of multi-subject diffusion data with tract-based spatial statistics. *Nature Protocols*, *2*, 499–503. https://doi.org/10.1038/nprot.2007.45

Song, S. K., Yoshino, J., Le, T. Q., Lin, S. J., Sun, S. W., Cross, A. H., & Armstrong, R. C. (2005). Demyelination increases radial diffusivity in corpus callosum of mouse brain. *Neuroimage*, *26*, 132–140. https://doi.org/10.1016/j.neuroimage.2005.01.028

Tiego, J., Testa, R., Bellgrove, M. A., Pantelis, C., & Whittle, S. (2018). A hierarchical model of inhibitory control. *Frontiers in Psychology*, *9*, 1339. https://doi.org/10.3389/fpsyg.2018.01339

Tovar-Moll, F., Monteiro, M., Andrade, J., Bramati, I. E., Vianna-Barbosa, R., Marins, T., Rodrigues, E., Dantas, N., Behrens, T. E. J., de Oliveira-Souza, R., Moll, J., & Lent, R. (2014). Structural and functional brain rewiring clarifies preserved interhemispheric transfer in humans born without the corpus callosum. *Proceedings of the National Academy of Sciences*, *111*, 7843–7848. https://doi.org/10.1073/pnas.1400806111

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI)*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (2003). *Manual for the Wechsler Intelligence Scale for Children-IV*. San Antonio, TX: The Psychological Corporation.

Zhang, H., Zhang, J., & Kornblum, S. (1999). A parallel distributed processing model of stimulus-stimulus and stimulus-response compatibility. *Cognitive Psychology*, *38*, 386–432. https://doi.org/10.1006/cogp.1998.0703

https://doi.org/10.1017/S1355617723000218 Published online by Cambridge University Press