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Title: The five minute Apgar score and childhood school outcomes.

Short title: Apgar scores and school outcomes.

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Abbreviations

AEDC – Australian Early Developmental Census

NAPLAN – National Assessment Program – Literacy and Numeracy

Abstract

Aim: To examine the association between Apgar score at five minutes and childhood developmental and educational outcome.

Methods: A population-based data linkage study of births ≥37 weeks' gestation linked to developmental outcomes at preparatory school and educational outcomes at school grades 3, 5, and 7 in Victoria, Australia. Multivariable logistic regressions and generalised estimating equations were employed

Results: There were 167,126 singleton infants with developmental results and 392,933 singleton infants with at least one educational result. There was an inverse relationship between Apgar score at five minutes and poor developmental and educational outcomes, with the worst outcomes among Apgar scores of 0-3. Apgar scores of 7, 8, and 9 were all associated with poorer developmental outcomes (aOR=1.31, 95% CI:1.12-1.54; aOR=1.17, 95% CI:1.05-1.29; aOR=1.08, 95% CI:1.02-1.13 respectively), while Apgar scores of 7 and 8 were associated with poorer educational outcomes at grades 3, 5, and 7. With progression through grades 3, 5, and 7, the extent of the difference in educational outcomes diminished (e.g. for Apgar scores of 0-3: aOR=3.33, 95% CI:1.85-6.00 in grade 3 and aOR=1.49, 95% CI:0.75-2.96 in grade 7).

Conclusion: Apgar scores below 10 at five minutes are associated with poorer developmental and educational outcomes in school.

Keywords: Apgar, childhood, development, school, neonatal

Key notes

- An Apgar score from 0-3 has been defined as a low score, 4-6 as moderately low, and 7 to 10 as normal.
- We show Apgar scores below 10 at five minutes are associated with poorer developmental and educational achievement in school across a range of Apgar scores at five minutes.
- Among children with low Apgar scores, there was catch-up in educational ability over time.

INTRODUCTION

The Apgar score has been widely embedded into clinical practice as a rapid assessment of the newborn's physical condition.[1] Its predictive value for these neonatal outcomes is well known.[2] Apgar scores below four are associated with a 359-fold increased risk of early neonatal death.[2] Apgar scores of 7, 8, and 9 at five minutes have also been associated with an increased risk of neonatal mortality, neonatal infections, neonatal respiratory distress, and hypoxic-ischaemic encephalopathy.[3,4] This demonstrates the utility of the Apgar score in predicting outcomes immediately after birth.

There has been growing interest in the predictive performance of Apgar scores for longer-term childhood outcomes. This comes in the face of international bodies suggesting the limitations of Apgar scores in predicting neurologic outcome.[5] Others have shown that risks of special needs, cerebral palsy, and epilepsy are all increased with Apgar scores within the normal range.[6-8] This provides evidence of milder changes to neurological function that occur with Apgar scores closer to 10, which may only be detectable as a child grows older and recognised at a population level.

In this study, we sought to explore the association between the five minute Apgar score of term infants and school outcomes.

METHODS

Study population

We conducted a retrospective, population-based cohort study using data from the Victorian Perinatal Data Collection. We analyzed singleton livebirths at ≥37 weeks' gestation born to women in Victoria, Australia, excluding all known moderate or major congenital anomalies. These data were probabilistically linked to childhood developmental records from the Australian Early Developmental Census (AEDC) and childhood educational records from the National Assessment Program – Literacy and Numeracy (NAPLAN) by the Centre for Victorian Data Linkage based on a range of personal identifiers. Only de-identified data were provided to the researchers. The maternal and perinatal characteristics of the linked population was similar to all births born during the study period.[9]

The AEDC is a nationwide triennial census first implemented in 2009 for first year full-time school students (ages 4 to 6 years). It is based on the validated Early Development Instrument developed in Canada.[10] Teachers assess and record information on nearly 100 characteristics for each child. These are combined to calculate a score from 0 to 10 for each of five domains: physical health and wellbeing, social competence, emotional maturity, language and cognitive skills, and communication and general knowledge. AEDC records for all four test years – 2009, 2012, 2015, and 2018 – were linked to the Victorian Perinatal Data Collection study population.

Educational outcomes were obtained from NAPLAN, an annual nationwide assessment of students in grades 3 (ages 7-9 years), 5 (ages 9-11 years), 7 (ages 11-13 years), and 9 (ages 13-15). The test assesses five domains: grammar and punctuation, numeracy, reading, spelling, and writing. Children are marked as above, at, or below the National Minimum Standard for each domain. The National Minimum Standard represents the benchmark for the basic level of knowledge and understanding needed to function at that grade and is standardized across grade

levels. NAPLAN data from children who undertook grade 3 between 2011-2019, grade 5 between 2013-2019, and grade 7 between 2015-2019 were linked to the Victorian Perinatal Data Collection study population.

Outcomes and covariates

The primary developmental outcome was defined as a developmentally vulnerable child on at least two of the five AEDC domains. Developmentally vulnerable was defined as being in the bottom 10th centile on a given domain. The primary educational outcome was defined as a child who either scored below the National Minimum Standard on at least two of the five NAPLAN domains or was exempt from sitting the NAPLAN (those with a substantial intellectual disability or co-existing conditions that severely limited their capacity to participate in the tests). This definition is consistent with formal NAPLAN reporting[11] and other uses of these data.[12]

Maternal, pregnancy, and child characteristics recognized as potential confounders were identified. These included infant sex, gestation at birth (in weeks), birthweight centile (<10th centile, 10th to <90th centile, ≥90th centile), hospital type (public, private, private midwife), parity (0, 1, ≥2), maternal age (younger than 20, 20-24, 25-29, 30-34, 35-39, 40-44, 45+ years), socioeconomic status, maternal Indigenous status, maternal region of birth, and English as a second language. Birthweight centiles were defined using Australian national birthweight standards.[13] For AEDC outcomes, socioeconomic status was assigned using the Socioeconomic Indexes for Area quintiles. For NAPLAN outcomes, the highest parent educational level and occupation assigned at grade 3 were used to proxy for socioeconomic status. English as a second language was

available for AEDC data only. Maternal indigenous status refers to women who self-identify as being of Aboriginal and/or Torres Strait Islander origin.

Statistical analyses

We first tabulated the maternal and pregnancy characteristics of infants by their Apgar score at five minutes. Categorical variables were reported as absolute numbers and percentages and compared using a Chi-square test of independence. Gestation at birth and birthweight were reported as median and interquartile range, and compared using Kruskal-Wallis test.

We then explored the association between Apgar score at five minutes and developmental and educational outcome at each grade level separately. Apgar scores were examined as categories (0-3, 4-6, 7, 8, 9, 10). Multivariable logistic regression models were used to compare groups, adjusting for available confounders. After assessing the primary developmental and educational outcome, individual domains were explored. Because scores were available for the educational domains, multivariable linear regression models were employed. Assumptions of normality of the residuals and homogeneity of variance were verified by inspection of residuals versus fitted plots.

Some infants had valid NAPLAN test data for all grades 3, 5, and 7, allowing for longitudinal analysis for the primary educational outcome. We used generalized estimating equations with an autoregressive correlation matrix to fit logistic regression models to the repeat NAPLAN outcomes within individuals and calculated robust standard errors. All available potential confounders were included in the models. Grade level was also added as a covariate to adjust for any changes in the threshold to defining the National Minimum Standard across the NAPLAN test

years. An interaction term between Apgar score at five minutes and grade level was considered to assess within-individual change across NAPLAN tests. A Wald test was performed and, if significant, the interaction term was retained in the model and changes from grade 3 to grade 7 were summarized.

Individuals with missing Apgar scores at five minutes, gestation, birthweight, birth status, and labor type were excluded. Data in other variables were excluded case-wise. <0.1% of Apgar scores at five minutes were missing, <0.1% of gestations, 0.1% of birthweights, <0.1% of birth statuses, <0.1% of labor types, <0.1% of parities, 0.7% of maternal country of births, 0.3% of maternal Indigenous statuses, 4.7% of AEDC scores and 0.2% of Socioeconomic Indexes for Area categories, 3.6%, 2.2%, and 1.5% of grade 3, 5, and 7 NAPLAN scores respectively, 2.0% of parent occupations, and 2.3% of parent educational levels. A P-value < .05 was considered statistically significant (two-tailed test).

Analyses were performed on Stata version 14 (StataCorp, College Station, Texas, USA). Ethical approval was provided by the Department of Health and Human Services Research Ethics Committee (#13/18).

RESULTS

In total, there were 167,126 singleton infants born at term with developmental results at school entry and 392,933 singleton infants born at term with at least one educational result at grades 3, 5, or 7. Of all infants with either a developmental or educational result, 412 (0.1%) had an Apgar score of 0 to 3, 3,991 (0.9%) had an Apgar score of 4 to 6, 5,309 (1.2%) had an Apgar score of 7, 17,075 (3.8%) had an Apgar score of 8, 324,583 (72.6%) had an Apgar score of 9, and 95,909 (21.4%) had an Apgar score of 10 at five minutes.

Table 1 presents the maternal and pregnancy characteristics of infants by their Apgar score at five minutes. Compared to infants with an Apgar score of 10 at five minutes, infants with lower Apgar scores were more commonly born to nulliparous women, to women younger than 20 years of age, to Indigenous women and women born in South Asia, South-East and East Asia, and Africa, and in public hospitals (P<0.001). They were also more likely to have a birthweight <10th centile and be admitted to the neonatal intensive care unit (P<0.001).

There was an inverse relationship between Apgar score at five minutes and the proportion of infants with poor developmental and educational outcomes, with the least favourable outcomes among infants with an Apgar score of 0 to 3, compared to those with an Apgar score of 10, but increasingly favourable outcomes seen with Apgar scores closer to 10 (Figure 1). This pattern was also evident after adjusting for potential confounders, even for Apgar scores of 7, 8, and 9 (Table 2).

The association between Apgar score at five minutes and individual developmental and educational domain, using a dichotomous outcome, was explored in supporting information Table S1. Compared to an Apgar score of 10, decreasing Apgar score at five minutes remained strongly associated with poorer outcome, and this relationship was consistent across all the domains and grade levels, though some groups may have been underpowered. When test scores on the individual educational domains were explored, Apgar scores between 7 and 9 had significant differences in adjusted mean score across the grade levels compared to Apgar scores of 10, and there was a noticeable difference between Apgar scores of 8 and 9 at five minutes (supporting information Table S2).

A valid NAPLAN result at all three grade levels was available for 163,716 infants, allowing for longitudinal analysis of this cohort. A significant interaction was found between Apgar score at five minutes and NAPLAN grade level ($P = 0.02$). The interaction term showed that, with progression through grades 3, 5, and 7, the extent of the difference in educational outcomes among each group of Apgar scores at five minutes diminished (Figure 1). This "catch-up" was mostly driven by infants with an Apgar score of 0-3 at five minutes (aOR=3.33, 95% CI:1.85-6.00 in grade 3 and aOR=1.49, 95% CI:0.75-2.96 in grade 7) (Figure 2).

DISCUSSION

Here we demonstrate a graded, inverse relationship between Apgar score at five minutes and poorer developmental outcome at school entry and poorer educational outcome throughout primary school and early high school. Nonetheless the longitudinal analysis showed evidence of "catch-up" in educational outcome with progression through grades 3, 5, and 7 among infants with an Apgar score of 0 to 3 at five minutes. Our findings highlight that, despite the controversies regarding the utility of the Apgar score, it is a widely used clinical tool which is associated with future neurodevelopmental outcome.

Strong associations have been reported between Apgar scores below 7 and cognitive impairment, special needs, cerebral palsy, and epilepsy.[6-8] But it is not just low Apgar scores. These association have been shown to persist in the range of Apgar scores considered normal.[6-8] Our findings provide evidence that this association applies to both developmental and educational achievement in school across a range of Apgar scores at five minutes, with significance in even a single digit change in Apgar score from the optimal value of 10 at five minutes for the future

neurodevelopmental integrity of the child. Our findings suggest that the Apgar score could be combined with other predictive variables to identify children at risk of neurodevelopmental delay and learning difficulties in school who might benefit from appropriate supports.

Within the school outcomes analysed, we did not find that lower Apgar scores affected a specific domain or area of child neurodevelopment. Instead, the entire spectrum of developmental and educational ability was affected in a graded fashion with decreasing Apgar score. This suggests that there may be value in investing in interventions that target gross childhood skills, such as language, behavioural, social, and learning areas. Others have suggested that interventions targeting parent-infant relationships could carry benefit.[14] We also found that, among children with Apgar scores of 0 to 3, there was evidence of "catch-up" in their academic ability with increasing age between primary school and early high school. This narrowing of the gap is welcomed. It provides evidence of cognitive and neurological resilience within the most vulnerable children. Others have shown a similar finding with regard to fetal growth restriction.[9,14] However "catch-up" was not observed for the other Apgar scores above 3 at five minutes. Their more modest risk of educational deficit in early primary school was sustained into early high school. This suggests that some childhood academic differences may not wash out over time The next steps will be to identify those infants most at risk before birth, using both Apgar and other variables, and implement neuroprotective interventions pre- and postnatally.

Limitations

This study had several limitations. Apgar scores are prone to significant interobserver variability,[15] though our findings are in keeping with other international studies,[16] and misclassification would occur independent of the child's school outcome. While we did not have data on Apgar

scores at one minute, this is less problematic because Apgar scores at five minutes are better predictors of outcome.[17] Australian hospitals do not routinely collect data on Apgar scores at ten minutes. Many factors contribute to academic success for which we could not adjust. Detailed information on smoking during pregnancy and maternal body mass index were not available, nor was information on the management of infants with low Apgar scores at five minutes was not available. Some have suggested that the use of neonatal interventions may attenuate the association between Apgar scores and adverse outcomes.[18] We also did not have access to post-exposure variables such as additional supports that may have been provided to children as they grew older. Though this study included a large number of infants with school results, the small number of infants within analyzed subgroups means that some results would have been underpowered.

CONCLUSION

Apgar scores below 10 at five minutes are associated with poorer developmental ability at school entry and educational ability in both primary school and early high school.

Figure Legend

Figure 1. Rate of poor developmental (in preparatory school) and educational outcome (in grades 3, 5, and 7) by Apgar score at five minutes.

Figure 2. Population-averaged adjusted odds ratio of poor educational outcome by Apgar score at five minutes for longitudinal cohort (i.e. infants who had valid Grade 3, Grade 5, and Grade 7 NAPLAN results).

Author statement

RJS conceived the study, acquired data, performed data analyses, interpreted the data, drafted the manuscript, and contributed to revision of the manuscript. EMW conceived the study, acquired the data, interpreted the data, and contributed to revision of the manuscript. PGD conceived the study, interpreted the data, and contributed to revision of the manuscript. DLR conceived the study, performed data analyses, interpreted the data, and contributed to revision of the manuscript. MF conceived the study, interpreted the data, and contributed to revision of the manuscript. M-AD conceived the study, acquired the data, performed data analyses, interpreted the data, and contributed to revision of the manuscript. All authors approved the final version of the manuscript to be published.

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	Apgar score 0-3	Apgar score 4-6	Apgar score 7	Apgar score 8	Apgar score 9	Apgar score 10	p-value
Parity							
0	228 (55.3)	2283 (57.2)	2937 (55.3)	8819 (51.6)	138439 (42.7)	38193 (39.8)	<0.001
1	113 (27.4)	1045 (26.2)	1431 (27.0)	5074 (29.7)	114967 (35.4)	36752 (38.3)	
≥2	71 (17.2)	663 (16.6)	941 (17.7)	3182 (18.6)	71146 (21.9)	20957 (21.9)	
Maternal age, years							
Younger than 20	16 (3.9)	120 (3.0)	147 (2.8)	419 (2.5)	6279 (1.9)	1351 (1.4)	<0.001
20-24	54 (13.1)	508 (12.7)	651 (12.3)	1899 (11.1)	33807 (10.4)	7676 (8.0)	
25-29	118 (28.6)	1056 (26.5)	1443 (27.2)	4468 (26.2)	82084 (25.3)	21096 (22)	
30-34	122 (29.6)	1350 (33.8)	1769 (33.3)	5990 (35.1)	117594 (36.2)	36858 (38.4)	
35-39	83 (20.1)	775 (19.4)	1056 (19.9)	3470 (20.3)	69955 (21.6)	23938 (25)	
40-44	16 (3.9)	174 (4.4)	234 (4.4)	806 (4.7)	14219 (4.4)	4782 (5.0)	
≥45	3 (0.7)	8 (0.2)	9 (0.2)	23 (0.1)	645 (0.2)	208 (0.2)	
Maternal Indigenous status	7 (1.7)	41 (1.0)	33 (0.6)	145 (0.9)	2219 (0.7)	560 (0.6)	<0.001
Maternal region of birth							
Australia or New Zealand	308 (75.3)	2978 (75.2)	4115 (78.0)	13137 (77.6)	239900 (74.4)	77318 (81.0)	<0.001
Africa	2 (0.5)	129 (3.3)	124 (2.3)	417 (2.5)	7721 (2.4)	1527 (1.6)	
South Asia	27 (6.6)	209 (5.3)	246 (4.7)	725 (4.3)	15646 (4.9)	2226 (2.3)	
South-East and East Asia	40 (9.8)	307 (7.8)	326 (6.2)	1094 (6.5)	27671 (8.6)	5867 (6.1)	
Western Asia	6 (1.5)	81 (2.0)	81 (1.5)	346 (2.0)	7451 (2.3)	1487 (1.6)	
Europe	15 (3.7)	184 (4.6)	265 (5.0)	877 (5.2)	17153 (5.3)	4995 (5.2)	
Other	11 (2.7)	73 (1.8)	121 (2.3)	337 (2.0)	6716 (2.1)	2076 (2.2)	
Hospital type	334 (81.1)	3202 (80.3)	4116 (77.5)	12541 (73.5)	228094 (70.3)	56458 (58.9)	<0.001

Public Private Private midwife	78 (18.9) 0 (0.0)	778 (19.5) 10 (0.3)	1190 (22.4) 3 (0.1)	4514 (26.4) 19 (0.1)	95889 (29.6) 512 (0.2)	38936 (40.6) 455 (0.5)	
Labour type							
Spontaneous	248 (60.2)	2281 (57.2)	2997 (56.5)	9388 (55.0)	192000 (59.2)	50734 (52.9)	<0.001
Induction of labour	121 (29.4)	1316 (33.0)	1732 (32.6)	5278 (30.9)	82903 (25.5)	22464 (23.4)	
Pre-labour caesarean section	43 (10.4)	394 (9.9)	580 (10.9)	2409 (14.1)	49680 (15.3)	22711 (23.7)	
Gestation, weeks'; median (IQR)	40 (39-40.5)	40 (39-40)	40 (38-40)	39 (38-40)	39 (38-40)	39 (38-40)	<0.001
Birthweight, grams; median (IQR)	3457 (3138-3820)	3460 (3125-3800)	3482 (3130-3830)	3480 (3150-3820)	3460 (3160-3780)	3465 (3170-3770)	0.004
Birthweight centile							
<10th centile	57 (13.8)	518 (13.0)	658 (12.4)	1834 (10.7)	29414 (9.1)	7367 (7.7)	<0.001
10th to <90th centile	304 (73.8)	2983 (74.7)	3963 (74.6)	13035 (76.3)	259979 (80.1)	78313 (81.7)	
≥90th centile	51 (12.4)	490 (12.3)	688 (13.0)	2206 (12.9)	35190 (10.8)	10229 (10.7)	
NICU admission	52 (12.7)	258 (6.5)	135 (2.6)	144 (0.8)	373 (0.1)	59 (0.1)	<0.001

Table 1. Maternal and pregnancy characteristics (n (%)), stratified by Apgar score at five minutes, for entire study population (i.e. infants who had either a developmental or an educational result).

[a] Percentages on valid data only. P-values calculated using Chi-square test of independence comparing results in each row.

	0-3	4-6	7	8	9	10
DV on 2+ domains on AEDC [b]	1.36 (0.79-2.32)	1.13 (0.95-1.36)	1.31 (1.12-1.54)	1.17 (1.05-1.29)	1.08 (1.02-1.13)	ref
Below NMS on 2+ domains in Grade 3 NAPLAN [c]	2.20 (1.47-3.27)	1.57 (1.35-1.83)	1.21 (1.05-1.40)	1.25 (1.15-1.37)	1.02 (0.97-1.06)	ref
Below NMS on 2+ domains in Grade 5 NAPLAN [c]	1.37 (0.82-2.30)	1.36 (1.14-1.61)	1.36 (1.17-1.57)	1.13 (1.03-1.24)	1.01 (0.97-1.06)	ref
Below NMS on 2+ domains in Grade 7 NAPLAN [c]	1.52 (0.83-2.78)	1.37 (1.11-1.70)	1.18 (0.99-1.42)	1.29 (1.16-1.43)	1.04 (0.98-1.09)	ref

Table 2. Adjusted odds ratio (with 95% confidence interval) of poor developmental and educational outcome by Apgar score at five minutes.

[a] DV = developmentally vulnerable; NMS = National Minimum Standard

[b] Adjusted for infant sex, gestation at birth, birthweight centile, parity, maternal age, maternal Indigenous status, socioeconomic status, maternal region of birth, hospital type, and English as a second language

[c] Adjusted for infant sex, gestation at birth, birthweight centile, parity, maternal age, maternal Indigenous status, parent occupational level, parent educational level, maternal region of birth, and hospital type

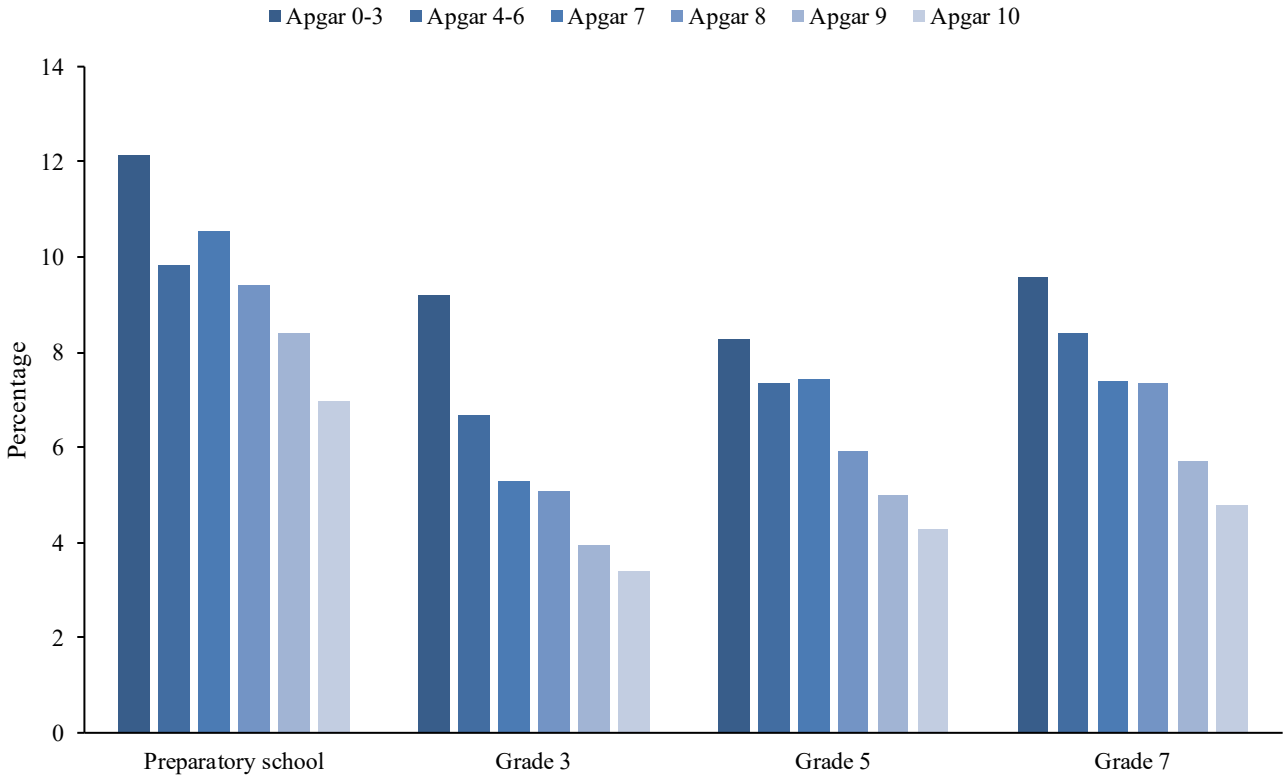

Figure 1. Rate of poor developmental (in preparatory school) and educational outcome (in grades 3, 5, and 7) by Apgar score at five minutes.

[a] Percentages on valid data only.

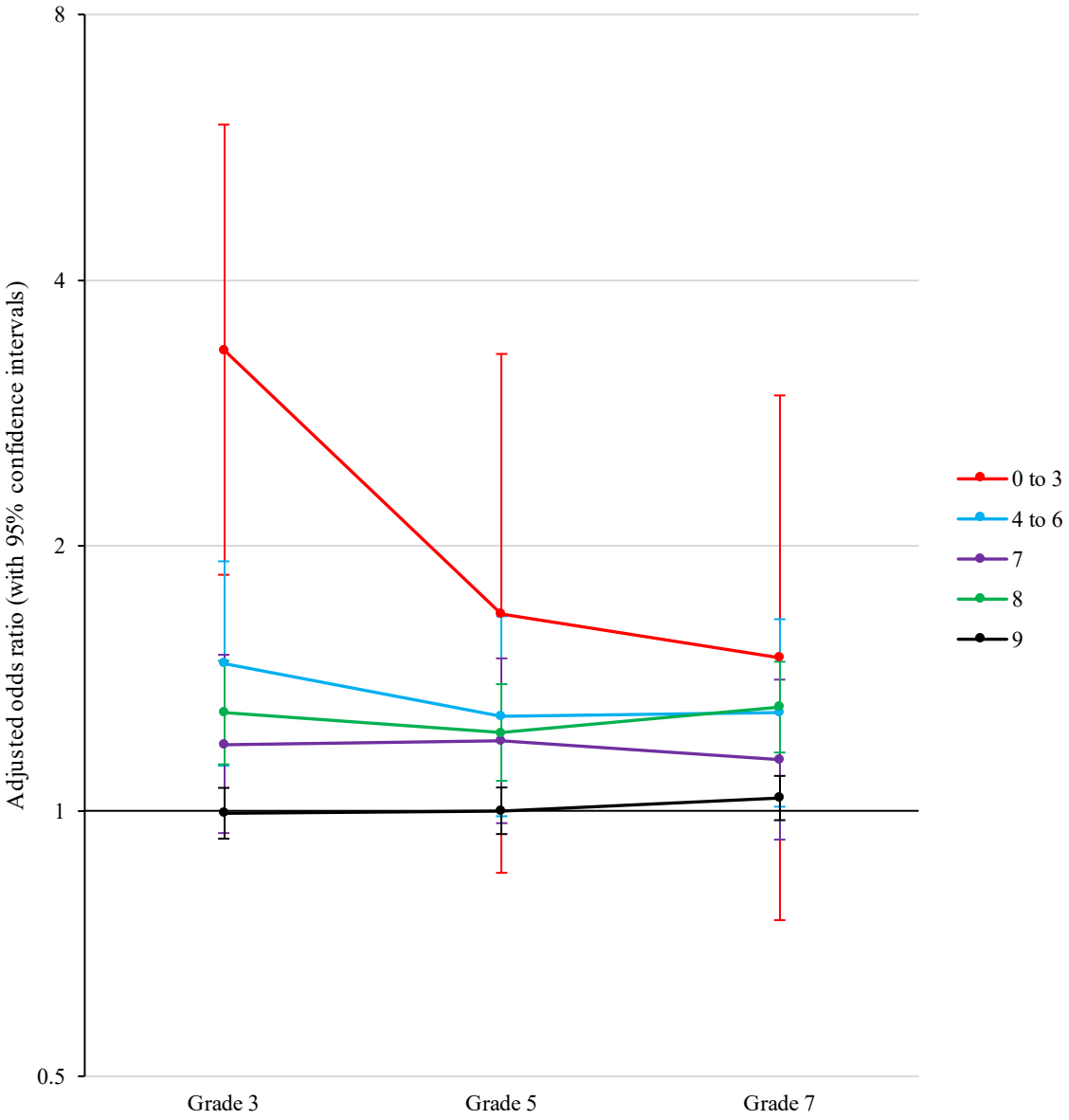

Figure 2. Population-averaged adjusted odds ratio of poor educational outcome by Apgar score at five minutes for longitudinal cohort (i.e. infants who had valid Grade 3, Grade 5, and Grade 7 NAPLAN results).

[a] Reference group is Apgar of 10 at five minutes.

[b] Adjusted for infant sex, gestation at birth, birthweight centile, parity, maternal age, maternal Indigenous status, parent occupational level, parent educational level, maternal region of birth, hospital type, NAPLAN grade level, and the interaction between Apgar score at five minutes and NAPLAN grade level