Appendix

Inhibitory Control Development from Infancy: Identifying Neural Correlates and Mapping Behavioural Trajectories into Early Childhood

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COVID-19 Impact Statement

The onset of the COVID-19 pandemic in March 2020 fundamentally impacted the shape and direction of my DPhil research and, ultimately, my doctoral thesis. In this foreword, I will provide an overview of the obstacles my research has faced because of the pandemic and what I have done to combat these challenges.

Before the pandemic (September 2019 – March 2020)

Starting my DPhil in September 2019 allowed six months of 'normality', which involved me running participant testing sessions as part of the Oxford Early Executive Functions (OEEF) study, led by my supervisor Dr Karla Holmboe. This study required infants and toddlers to visit the Oxford University Babylab at several time points from 10-months to 2½ years of age. Before the pandemic, 144 10-month-old infants attended at least one testing session at the Babylab, and of these, 78 infants returned for sessions at the 16-month time point. The onset of the COVID-19 pandemic and the first national lockdown in March 2020 meant that all in-person participant sessions had to be cancelled. This had a significant impact on the OEEF study since no in-person data collection could take place from March 2020 – July 2021, and as such, the longitudinal study in its original format had to be discontinued.

It was my original intention that my doctoral research would focus on the toddler portion of the OEEF study (May 2020 – January 2022), when the children in the cohort would turn 2 and 2½ years old. I planned to pilot a new toddler working memory task for use with functional near-infrared spectroscopy (fNIRS) that I had been developing with collaborators (Dversgdal - software, Kaldy & Cheng – task methodology). Pilot test sessions had already been booked to start in March 2020 and were planned to continue until May 2020. This developmental longitudinal research is incredibly time-sensitive, and children will not stop getting older while our lab is closed. Since data had already been collected from these participants in infancy, we needed to collect data from these *same* children at 2 and 2½ years of age. As these age milestones passed whilst we were still in lockdown, not only was a significant amount of data lost, but the piloting and task development efforts had been futile, as the task had not been piloted and was not designed for use with older children.

During the pandemic (March 2020 – March 2021)

During this period of national lockdowns and local COVID-19 restrictions, the laboratory remained closed, and no participants were tested from March 2020 – July 2021. In response to the unprecedented global pandemic and the uncertainty of the OEEF longitudinal study, my supervisor and I decided that it would be extremely beneficial to capture the impact of the pandemic on the development of the children in the OEEF cohort and their families. We developed the 'COVID-19 Impact Questionnaire' which examined the impact of COVID-19 on families with young children in five key areas: physical health, mental health, finances and employment, familial relationships, and the child's socioemotional and behavioural functioning. This questionnaire, along with questionnaire measures of maternal depression and infant/child temperament, was sent to participants in the OEEF study and previous pilot participants at four time points throughout the pandemic: April 2020 (first national lockdown), November 2020 (second national lockdown), July 2021 (just as all government COVID restrictions were lifted), and November 2022 (at the 'end' of the pandemic). The results of this work from the April and November 2020 time points were published in *Infant and Child Development* in June 2022 (Fiske, Scerif, et al., 2022), and indicated no significant negative impacts of the pandemic on maternal depressive symptoms and infant temperament across the first six months of the pandemic. Data collected at the July 2021 and November 2022 assessment points have been organised and prepared for analysis, which will take place following the submission of the current thesis. With this longitudinal data, it will be possible to examine the long-term impacts of the pandemic on these aspects of maternal mental health and child temperament. However, this work does not fit within the scope of the current thesis (which focuses on inhibitory control development in the first four years of life) and so is not included here.

Alongside this work and whilst the lab was closed, I was able to prepare, analyse and report on behavioural and fNIRS data that had already been collected from a cohort of 135 10-month-old infants from the OEEF study before the pandemic (a proportion of which I had collected myself). During this time, I trained two undergraduate interns to video code the behavioural data, I attended webinars and online courses to familiarise myself with the pre-processing steps of fNIRS data, and I worked with a collaborator to learn two statistical techniques for the analysis of fNIRS data. This data has now been coded and analysed and was published in *NeuroImage* in August 2022 (Fiske, de Klerk, et al., 2022). This data is reported in Chapter 4 of the current thesis. Since much of my thesis centres on fNIRS, this was an excellent opportunity to gain experience and skills in analysing fNIRS data that I continued to use throughout my doctoral research.

Returning to ‘normality’ (March 2021 – November 2021)

As the COVID-19 restrictions and government guidelines began to ease in mid-2021, it was decided by the Medical Science Division Ethics Board that in-person test sessions could resume. Whilst the original time points in the OEEF study had been lost because of the time that passed during the lockdowns (the children did not stop getting older!), it was possible to invite this cohort of children back for sessions in the Babylab when they turned 3½ years of age (November 2021 – November 2022). Once a revised ethics application had been approved, I began pilot testing in July 2021, ahead of the first children in the OEEF turning 3½ in November 2021.

During this period, I prepared a full study protocol that included a task battery of age-appropriate EF tasks suitable for 3½-year-old participants. This involved reviewing the literature, trialling tasks with pilot participants, and training an undergraduate intern on task administration and scoring. Additionally, this required contacting families who had previously taken part in pilot test sessions for the OEEF study (and recruiting new pilot families) and arranging for test sessions to take place in the Babylab. Pilot testing involved two visits to the Babylab (spaced approximately one week apart) and each lasted around 1 hour and 30 minutes. In total, 32 pilot participants were tested between the end of July and the end of November 2021. The pilot testing phase was fundamental in the appropriate selection of EF tasks (finding out what works and what doesn’t!), determining a suitable task order, and finalising the administration protocol ahead of the start of longitudinal testing.

Business as usual (November 2021 – November 2022)

As things returned to normal, the 3½ year assessment point of the OEEF longitudinal study was up and running (with some COVID restrictions in place, as per university guidance). Across this period, an undergraduate placement student and I tested 94 children (each for two sessions) on the EF task battery that we had assembled – data from this part of the study are reported in Chapters 6 and 7 of the current thesis.

Appendix A

Chapter 2: Methodological Approach to the Study of Early Executive Function Development

1. Reference List for Behavioural Tasks and Questionnaires

A reference list is provided below for the citations used in Table 5 (Overview of Assessment Methods) when listing the behavioural tests, questionnaires, and standardised assessment methods used in this thesis.

References

Fiske, A., de Klerk, C., Lui, K. Y., Collins-Jones, L., Hendry, A., Greenhalgh, I., ... & Holmboe, K. (2022). The neural correlates of inhibitory control in 10-month-old infants: A functional near-infrared spectroscopy study. *NeuroImage, 257*, 119241. https://doi.org/10.1016/j.neuroimage.2022.119241

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Appendix B

Chapter 4: The Neural Correlates of Response Inhibition in 10-month-old Infants

1. Author Contribution Statement for Chapter 4 / Fiske et al. (2022)

The following are authors of the published article (Fiske, de Klerk, et al., 2022) that reports on the data presented in Chapter 4 of this thesis: **Abigail Fiske** (AF), University of Oxford; Carina de Klerk (CdK), University of Essex; Katie Y.K. Lui (KL), University of Bath; Liam Collins-Jones (LCJ), University College London; Alexandra Hendry (AHa), University of Oxford; Isobel Greenhalgh (IG), University of Cambridge; Anna Hall (AHa), University of Oxford, University College London; Gaia Scerif (GS), University of Oxford; Henrik Dvergsdal (HD), Nord University; Karla Holmboe (KH), University of Oxford, University of Bristol.

The contributions of each author to this published article are as follows:

- Conceptualisation - KH
- Task design – KH (behavioural ECITT), KH, CdK, HD (blocked ECITT)
- Software programming - HD
- Analysis plan – **AF**, CdK, KH
- Pre-registration – **AF**, CdK, GS, KH
- Data collection – **AF**, KH, AHa, IG, AHe, KL
- Video coding and coding protocol development – **AF**, KL
- Data curation – **AF**, KH, HD
- fNIRS Data processing and analysis – **AF**, CdK
- Statistical analysis – **AF**, CdK, KH
- fNIRS image reconstruction, channel localisation, head modelling – LCJ
- Writing – original draft - **AF**
- Writing – reviewing and editing – **AF**, KH, CdK, GS, AHe, Aha, HD, LCJ
- Supervision – KH, CdK, GS
- Project management and administration – KH
- Funding acquisition – KH, **AF**

2. Anatomical Labels of Channels in the fNIRS Probe

This work was completed by Dr Liam Collins-Jones for the published paper associated with this study (Fiske, de Klerk, et al., 2022). A description of the process undertaken to produce an age-appropriate head model, localise the channels in the fNIRS probe to their cortical positions on this head model and reconstruct an image of changes in haemodynamic concentration data on this head model, are described in Section 2.6.5. of the published article. **Table 1** below provides the anatomical label for each channel in the fNIRS probe in the 10-month study.

Table 1. Appendix B. Anatomical Labels of Channels in the fNIRS Probe at 10-months.

Channel	Hemisphere	Cortical Region
1	Left	'Inferior parietal gyrus (P2)'
2	Left	'Inferior parietal gyrus (P2)'
3	Left	'Superior parietal gyrus (P1)'
4	Left	'Inferior parietal gyrus (P2)'
5	Left	'Superior parietal gyrus (P1)'
6	Left	'Superior parietal gyrus (P1)'
7	Right	'Inferior parietal gyrus (P2)'
8	Right	'Angular gyrus (AG)'
9	Right	'Angular gyrus (AG)'
10	Right	'Inferior parietal gyrus (P2)'
11	Right	'Superior parietal gyrus (P1)'
12	Right	'Superior parietal gyrus (P1)'
13	Left	'Inferior frontal gyrus, triangular (F3T)'
14	Left	'Inferior frontal gyrus, triangular (F3T)'
15	Left	'Middle frontal gyrus (F2)'
16	Left	'Inferior frontal gyrus, triangular (F3T)'
17	Left	'Inferior frontal gyrus, triangular (F3T)'
18	Left	'Middle frontal gyrus (F2)'
19	Left	'Middle frontal gyrus (F2)'
20	Right	'Inferior frontal gyrus, triangular (F3T)'
21	Right	'Inferior frontal gyrus, triangular (F3T)'
22	Right	'Middle frontal gyrus (F2)'
23	Right	Inferior frontal gyrus, triangular (F3T)'
24	Right	'Middle frontal gyrus (F2)'
25	Right	'Middle frontal gyrus (F2)'
26	Right	'Middle frontal gyrus (F2)'
27	Left	'Inferior frontal gyrus, orbital (F3O)'
28	Left	'Middle frontal gyrus (F2)'

29	Left	'Middle frontal gyrus, orbital (F2O)'
30	Left	'Middle frontal gyrus (F2)'
31	Right	'Inferior frontal gyrus, orbital (F3O)'
32	Right	'Middle frontal gyrus, orbital (F2O)'
33	Right	'Middle frontal gyrus, orbital (F2O)'
34	Right	'Middle frontal gyrus (F2)'
35	Left	'Superior frontal gyrus, dorsolateral (F1)'
36	Left	'Superior frontal gyrus, dorsolateral (F1)'
37	Right	'Superior frontal gyrus, dorsolateral (F1)'
38	Right	'Superior frontal gyrus, dorsolateral (F1)'
39	Left	'Superior frontal gyrus, dorsolateral (F1)'
40	Left	'Superior frontal gyrus, medial (F1M)'
41	Right	'Superior frontal gyrus, dorsolateral (F1)'
42	Right	'Superior frontal gyrus, medial (F1M)'
43	Left	'Superior frontal gyrus, dorsolateral (F1)'
44	Left	'Superior frontal gyrus, medial orbital (F1MO)'
45	Right	'Superior frontal gyrus, dorsolateral (F1)'
46	Right	'Superior frontal gyrus, orbital (F1O)'

Note. The anatomical labels for each channel were created using the infant automated anatomical labelling (AAL) atlas presented by (Shi et al., 2011).

3. Parametric Test Assumptions

Each behavioural variable was tested for normality by examining the results of the Shapiro-Wilk test and the skewness (z-score) of the data; the results and conclusions of these tests are reported in **Table 2** below. The significance value of the Shapiro-Wilk test informs whether the data are normally distributed; if $p > .005$, this suggests that the data are normally distributed, but if $p < .005$, this suggests that the data may deviate from a normal distribution. According to Kim (2013), for samples with more than 50 and less than 300 participants, a z-scored skew > 3.29 would suggest the sample distribution is not normal. This criterion has been applied to the behavioural variables used in this study when determining normality. In cases where variables are not normally distributed and are skewed beyond an acceptable level, non-parametric tests will be conducted alongside parametric tests to check for convergence.

Similarly, each fNIRS variable was tested for normality before the repeated measures ANOVAs were conducted. The data meet the assumptions that the dependent variable (haemoglobin concentration) must be on a continuous scale and that the within-groups variable (condition) must have two or more groups (control, experimental). Due to the extremely high number of variables ($N = 1933$), it was not possible to test the dependent

variable (haemoglobin concentration data) for normality. The dependent variables are unlikely to be normally distributed due to the nature of the physiological data and the sheer number of variables. However, the repeated measures ANOVA is robust against violations of the normality assumption and so the risk of Type I error remains low. To control for the possibility of false positives, the Benjamini-Hochberg procedure for controlling the false discovery rate has been applied to these analyses (Benjamini & Hochberg, 1995). The sphericity of the data was tested using Mauchly's test of sphericity and data from all but one channel (Channel 15) did not meet the sphericity assumption. Therefore, the Greenhouse-Geisser degrees of freedom and *p*-values were reported to account for the lack of sphericity in all channels.

The fNIRS haemoglobin difference variables that were generated for the individual differences analyses were tested for normality by examining the results of the Shapiro-Wilk test and the skewness (z-score) of the data; the results and conclusions of these tests are reported in **Table 2** below.

Table 2. Appendix B. Normality Tests for the 10-month Dataset.

	Variable	*N*	Shapiro-Wilk (*p*)	Skew (z)	Conclusion
Behavioural ECITT (Session 1)	Mean inhibitory accuracy	128	.000	-1.59	Not normally distributed, acceptable skew
	Mean prepotent accuracy	128	.000	-3.64	**Not normally distributed, skew not acceptable**
	Accuracy inhibitory score	128	.028	0.60	Not normally distributed, acceptable skew
Blocked ECITT (Session 2)	Mean inhibitory accuracy	121	.000	-0.19	Not normally distributed, acceptable skew
	Mean prepotent accuracy	121	.000	-5.76	**Not normally distributed, skew not acceptable**
	Accuracy inhibitory score	121	.006	0.26	Not normally distributed, acceptable skew
Individual Differences	HbO_2 diff right DLPFC Bins 3 - 5	54	.403	-1.06	Normally distributed, acceptable skew
	HbO_2 diff right parietal Bins 3 - 5	48	.079	1.87	Normally distributed, acceptable skew
	HHb diff Channel 25 Bins 3 - 5	56	.100	2.38	Normally distributed, acceptable skew
	HHb diff right OFC Bins 4 - 6	57	.089	2.00	Normally distributed, acceptable skew
	Accuracy inhibitory Score	59	.029	0.35	Not normally distributed, acceptable skew

3.1. Results of Non-Parametric Tests

ECITT Condition Effects

Results of non-parametric related samples Wilcoxon signed rank tests were conducted to examine whether there was a significant difference in accuracy and reaction time between trial types. There was a significant difference in accuracy between trial types in both the behavioural ECITT in Session 1: $Z = 8.779$, $p < .001$, and the blocked ECITT in Session 2: $Z = 8.570$, $p < .001$. Results were in convergence with the results of parametric tests reported in Chapter 4.

Between-Session Consistency and Test Re-Test Reliability

Since the mean prepotent accuracy variable for both sessions was not normally distributed, a related samples Wilcoxon signed tank test was conducted: $Z = 4.230$, $p < .001$. Results aligned with the parametric *t*-test reported in Chapter 4. Since the mean prepotent accuracy variables for both sessions were not normally distributed, the non-parametric Spearman's rho correlation analysis was conducted. Results confirmed the test re-test reliability, although with a slightly smaller effect size: r_s (110) = .273, p = .004, *CI* = .079, .464.

Group Performance Differences

Results of independent samples Mann-Whitney U tests indicated that there was no significant difference in mean inhibitory accuracy: $Z = .215$, $p = .829$, mean prepotent accuracy: $Z = -1.149$, $p = .251$, and the accuracy inhibitory score: $Z = .415$, $p = .678$ between groups. These results align with the parametric test results reported in Chapter 4.

Individual Differences Analyses

Spearman's rho correlational analyses found no significant association between individual differences in the accuracy inhibitory score and HbO_2 difference in the right lateral PFC; r_s (57) = -.070, p = .298, *CI* = -.313, .158, and the right parietal cortex; r_s (53) = .071, p = .304, *CI* = .232, .336, in line with the parametric results. No significant association was found between the HHb difference in Channel 25 (right PFC) and the accuracy inhibitory score: r_s (54) = .216, p = .055, *CI* = -.050, .444. This contrasts with the results of Pearson's correlational analysis (reported in Chapter 4) which did indicate a significant association (p = .029).

4. fNIRS Group-Level Results: Main Effect of Time

Table 3 displays the results of the repeated measures ANOVAs that investigated which channels showed significant activation in task conditions compared to baseline (main effect of time), as defined by a significant increase in HbO_2 from baseline over the 35 s block time course. **Table 4** shows the results for the HHb chromophore, where a main effect of time is indicated by a significant decrease in HHb from baseline over time.

Table 3. Appendix B. Main Effect of Time (HbO_2) in the 10-month Dataset.

	Left hemisphere			Right hemisphere		
	Channel	*F*	*p*	Channel	*F*	*p*
Intraparietal Sulcus	1	13.045	**<.001***	7	25.757	**<.001***
	2	6.205	**.001***	8	16.789	**<.001***
	3	3.996	**.016***	9	14.259	**<.001***
	4	6.546	**.001***	10	20.646	**<.001***
	5	4.449	**.014***	12	4.241	**.016***
	6	2.990	**.044**			
Prefrontal Cortex	13	9.058	**<.001***	20	6.018	.002*
	14	21.715	**<.001***	21	7.765	**<.001***
	16	9.011	**<.001***	22	30.804	**<.001***
	17	30.417	**<.001***	23	10.211	**<.001***
	18	9.907	**<.001***	24	34.045	**<.001***
	19	9.812	**<.001***	25	36.921	**<.001***
	27	3.519	**.023***	26	33.881	**<.001***
	28	3.259	**.026***	31	11.559	**<.001***
	29	.719	.545	32	24.829	**<.001***
	35	.905	.414	33	13.502	**<.001***
	36	1.509	.225	37	7.770	**.002***
	39	.438	.636	38	10.639	**<.001***
	40	.446	.686	41	2.442	.094
	43	.587	.588	42	6.492	**.001***
	44	2.094	.129	45	3.605	**.029***
				46	1.224	.302

Note. Statistically significant results are highlighted in bold. * = significant at $p < .05$, corrected for 84 comparisons.

Table 4. Appendix B. Main Effect of Time (HHb) in the 10-month Dataset.

	Left hemisphere			Right hemisphere		
	Channel	*F*	*p*	Channel	*F*	*p*
Intraparietal sulcus	1	4.209	**.011***	7	7.268	**<.001***
	2	3.044	**.038***	8	3.832	**.017***
	3	8.176	**<.001***	9	2.861	.056
	4	5.004	**.005***	10	13.228	**<.001***
	5	1.685	.179	12	.337	.761
	6	1.117	.339			
Prefrontal Cortex	13	3.819	**.014***	20	8.534	**<.001***
	14	8.775	**<.001***	21	2.785	.051
	16	7.134	**<.001***	22	27.368	**<.001***
	17	16.503	**<.001***	23	7.300	**<.001***
	18	10.422	**<.001***	24	20.272	**<.001***
	19	12.864	**<.001***	25	20.585	**<.001***

27	8.479	**<.001***	26	31.379	**<.001***
28	10.361	**<.001***	31	4.465	**.006***
29	5.547	**.001***	32	24.005	**<.001***
35	2.879	**.037***	33	19.668	**<.001***
36	4.265	**.007***	37	.908	**.422**
39	12.444	**<.001***	38	4.787	**.004***
40	12.389	**<.001***	41	5.442	**.002***
43	5.792	**.003***	42	5.225	**.004***
44	2.040	.132	45	8.818	**<.001***
			46	6.374	**.003***

Note. Statistically significant results are highlighted in bold. * = significant at $p < .05$, corrected for 84 comparisons.

5. Exploratory Brain-Behaviour Associations

Exploratory analyses (not pre-registered) were conducted to examine associations between behaviour (inhibitory accuracy, prepotent accuracy) and brain activation in the full sample of participants with valid fNIRS data ($N = 59$). Results are reported in **Table 5** below.

Table 5. Appendix B. Exploratory Longitudinal Brain-Behaviour Associations at 10-months.

Location	Channel	Accuracy Inhibitory Score	Inhibitory Accuracy	Prepotent Accuracy
R inferior parietal (HbO_2)	10	.081	.210	**.034**
R superior parietal (HbO_2)	12	.221	.162	.742
R DLPFC (HbO_2)	25	.377	.459	.280
R DLPFC (HHb)	25	.102	.121	.151
R DLPFC (HbO_2)	26	.071	**.032**	.383
R OFC (HbO_2)	32	.450	.310	.392
R OFC (HHb)	32	.263	.201	.593
R OFC (HHb)	33	**.016**	**.020**	.643

Note. The values in the third, fourth, and fifth columns in this table are two-tailed *p-values*. Significant results are highlighted in bold. Note that the significant effects did not survive correction for the FDR ($N = 24$ comparisons).

Appendix C

Chapter 5: Response Inhibition in the Transition to Toddlerhood: Neural Correlates and Behavioural Development

1. Author Contribution Statement for Chapter 5

The authors of the pre-registered study associated with Chapter 5 of this thesis (preprinted on PsyArXiv) are as follows: **Abigail Fiske (AF),** University of Oxford; Liam Collins-Jones (LCJ), University College London; Carina de Klerk (CdK), University of Essex; Katie Y.K. Lui (KL), University of Cambridge; Alexandra Hendry (AHa), University of Oxford; Isobel Greenhalgh (IG), University of Cambridge; Anna Hall (AHa), University of Oxford, University College London; Henrik Dvergsdal (HD), Nord University; Gaia Scerif (GS), University of Oxford; Karla Holmboe (KH), University of Oxford, University of Bristol.

The contributions of each author to this pre-registered study are as follows:

- Conceptualisation - KH
- Task design – KH (behavioural ECITT), KH, CdK, HD (blocked ECITT)
- Software programming - HD
- Analysis plan – **AF**, CdK, KH
- Pre-registration – **AF**, CdK, GS, KH
- Data collection – **AF**, KH, AHa, IG, AHe, KL
- Video coding and coding protocol development – **AF**, KL
- Data curation – **AF**, KH, HD
- fNIRS Data processing and analysis – **AF**, CdK
- Statistical analysis – **AF**, CdK, KH
- fNIRS image reconstruction, channel localisation, head modelling – LCJ
- Writing – original draft - **AF**
- Writing – reviewing and editing – **AF**, KH, CdK, GS, AHe, AHa, HD, LCJ
- Supervision – KH, CdK, GS
- Project management and administration – KH
- Funding acquisition – KH

2. Anatomical Labels of Channels in the fNIRS Probe

This work was completed by Dr Liam Collins-Jones for the pre-registered study (Fiske et al. in prep) associated with the data presented in Chapter 5 of the current thesis. **Table 6** below provides the anatomical label for each channel in the fNIRS probe in the 16-month study. Aside from Channel 32 (see below), the only other changes in anatomical labels from 10- to 16-months were in Channels 17 and 21, which were labelled as covering the inferior frontal gyrus, triangular at 10-months, and the middle frontal gyrus at 16-months.

As stated in the pre-registration: "*Note that a small change to the head modelling and channel localisation procedure was made for the 16-month dataset, such that there are some minor differences between the procedure used to localise channels at 10- and 16-months; see section 'Prior knowledge' for full details. This means that the label for Channel 32 (which is positioned on the border between the 'middle frontal gyrus' and the 'middle frontal gyrus, orbital' regions, according to the infant automated anatomical labelling atlas; Shi et al., 2011) has changed from the 'middle frontal gyrus, orbital' (as used in the 10-month paper; Fiske et al., 2022) to the 'middle frontal gyrus' label. Nevertheless, the position of this channel is closer to the right orbital region than the previously identified channels of interest in the right dorsolateral region (Channels 25 and 26; Fiske et al., 2022). Therefore, for the purposes of the analyses planned in this pre-registration, we consider Channel 32 to be part of the OFC and will use this label throughout our pre-registration. This also retains consistency in labelling between the current pre-registration and Fiske et al. (2022). MATLAB figures of the channel positions on the cortex at both 10- and 16-months are available to view here.*"

Table 6. Appendix C. Anatomical Labels of Channels in the fNIRS Probe at 16-months.

Channel	Hemisphere	Cortical Region
1	Left	'Inferior parietal gyrus (P2)'
2	Left	'Inferior parietal gyrus (P2)'
3	Left	'Superior parietal gyrus (P1)'
4	Left	'Inferior parietal gyrus (P2)'
5	Left	'Superior parietal gyrus (P1)'
6	Left	'Superior parietal gyrus (P1)'
7	Right	'Inferior parietal gyrus (P2)'
8	Right	'Angular gyrus (AG)'
9	Right	'Angular gyrus (AG)'
10	Right	'Inferior parietal gyrus (P2)'
11	Right	'Superior parietal gyrus (P1)'

12	Right	'Superior parietal gyrus (P1)'
13	Left	'Inferior frontal gyrus, triangular (F3T)'
14	Left	'Inferior frontal gyrus, triangular (F3T)'
15	Left	'Middle frontal gyrus (F2)'
16	Left	'Inferior frontal gyrus, triangular (F3T)'
17	Left	'Middle frontal gyrus (F2)'
18	Left	'Middle frontal gyrus (F2)'
19	Left	'Middle frontal gyrus (F2)'
20	Right	'Inferior frontal gyrus, triangular (F3T)'
21	Right	'Middle frontal gyrus (F2)'
22	Right	'Middle frontal gyrus (F2)'
23	Right	Inferior frontal gyrus, triangular (F3T)'
24	Right	'Middle frontal gyrus (F2)'
25	Right	'Middle frontal gyrus (F2)'
26	Right	'Middle frontal gyrus (F2)'
27	Left	'Inferior frontal gyrus, orbital (F3O)'
28	Left	'Middle frontal gyrus (F2)'
29	Left	'Middle frontal gyrus, orbital (F2O)'
30	Left	'Middle frontal gyrus (F2)'
31	Right	'Inferior frontal gyrus, orbital (F3O)'
32	Right	'Middle frontal gyrus (F2)'
33	Right	'Middle frontal gyrus, orbital (F2O)'
34	Right	'Middle frontal gyrus (F2)'
35	Left	'Superior frontal gyrus, dorsolateral (F1)'
36	Left	'Superior frontal gyrus, dorsolateral (F1)'
37	Right	'Superior frontal gyrus, dorsolateral (F1)'
38	Right	'Superior frontal gyrus, dorsolateral (F1)'
39	Left	'Superior frontal gyrus, dorsolateral (F1)'
40	Left	'Superior frontal gyrus, medial (F1M)'
41	Right	'Superior frontal gyrus, dorsolateral (F1)'
42	Right	'Superior frontal gyrus, medial (F1M)'
43	Left	'Superior frontal gyrus, dorsolateral (F1)'
44	Left	'Superior frontal gyrus, medial orbital (F1MO)'
45	Right	'Superior frontal gyrus, dorsolateral (F1)'
46	Right	'Superior frontal gyrus, orbital (F1O)'

Note. The anatomical labels for each channel were created using the infant automated anatomical labelling (AAL) atlas presented by Shi et al. (2011).

3. Parametric Test Assumptions

Each behavioural and fNIRS-related variable was tested for normality by examining the results of the Shapiro-Wilk test and the skewness (z-score) of the data; the results and conclusions of these tests are reported in **Table 7** below. Please see Appendix B3 for details about how these tests were conducted. Note that the sphericity of the fNIRS data was tested using Mauchly's test of sphericity and data from all but one channel (Channel 9) did not meet the sphericity assumption. Therefore, the Greenhouse-Geisser degrees of freedom and *p*-values were reported to account for the lack of sphericity in all channels.

Table 7. Appendix C. Normality Tests for the 16-month Dataset.

	Variable	*N*	Shapiro-Wilk (*p*)	Skew (z)	Conclusion
Behavioural ECITT (Session 1)	Mean inhibitory accuracy	77	<.001	0.24	Not normally distributed, acceptable skew
	Mean prepotent accuracy	77	<.001	-6.06	**Not normally distributed, skew not acceptable**
	Accuracy inhibitory score	77	<.001	0.25	Not normally distributed, acceptable skew
	Median inhibitory reaction time	66	<.001	14.27	**Not normally distributed, skew not acceptable**
	Median prepotent reaction time	66	<.001	7.45	**Not normally distributed, skew not acceptable**
Blocked ECITT (Session 2)	Mean inhibitory accuracy	81	<.001	0.12	Not normally distributed, acceptable skew
	Mean prepotent accuracy	81	<.001	-5.84	**Not normally distributed, skew not acceptable**
	Accuracy inhibitory score	81	.018	0.82	Normally distributed, normal skew
	Median inhibitory reaction time	77	<.001	6.98	**Not normally distributed, skew not acceptable**
	Median prepotent reaction time	77	<.001	4.25	**Not normally distributed, skew not acceptable**
Individual Differences	HHb diff Channel 6 Bins 2 – 5	39	.123	1.78	Normally distributed, normal skew
	HHb diff Channel 23 Bins 1 – 2	43	.131	2.04	Normally distributed, normal skew
	HbO_2 diff Channel 26 Bin 1	37	.861	0.41	Normally distributed, normal skew
	HHb diff Channel 28 Bins 1 – 4 and Bin 7	42	.006	3.56	**Not normally distributed, skew not acceptable**
	HHb diff Channel 29 Bins 1 – 2	42	.023	2.17	Not normally distributed, acceptable skew
	HHb diff Channel 33 Bins 1, 2 & 4	43	.315	-.723	Normally distributed, normal skew

3.1. Results of Non-Parametric Tests

ECITT Condition Effects

Results of non-parametric related samples Wilcoxon signed rank tests were conducted to examine whether there was a significant difference in accuracy and reaction time between trial types. Results were in convergence with the results of parametric tests reported in Chapter 5. There was a significant difference in accuracy between trial types in both the behavioural ECITT in Session 1: $Z = 6.186$, $p < .001$, $d = .79$, and the blocked ECITT in Session 2: $Z = 6.846$, $p < .001$, $d = .76$. Similarly, there was a significant difference in reaction time between trial types in both the behavioural ECITT in Session 1: $Z = -3.063$, $p = .002$, $d = .42$, and the blocked ECITT in Session 2: $Z = -4.697$, $p < .001$, $d = .54$.

Behavioural Development from 10- to 16-months

Results of Spearman's correlation analyses revealed that there was no significant association between performance (accuracy inhibitory score) on the behavioural ECITT (Session 1) at 10-months and 16-months: r_s (63) = -.122, $p = .166$, *CI* = -.387, .158, or on the blocked ECITT (Session 2) at 10- and 16-months: r_s (61) = .075, $p = .282$, *CI* = -.172, .306. Results were consistent with the results of Pearson's correlations (reported in Chapter 5). Results of non-parametric related samples Wilcoxon signed rank tests suggested that in the behavioural ECITT (Session 1), there was no significant difference in mean inhibitory accuracy: $Z = -.488$, $p = .626$, or in mean prepotent accuracy: $Z = 1.576$, $p = .115$ from 10- to 16-months. The same results were found for the blocked ECITT (Session 2), where there was no significant difference in mean inhibitory accuracy: $Z = .169$, $p = .866$ or in mean prepotent accuracy: $Z = 1.419$, $p = .156$ from 10- to 16-months. Results are in alignment with the parametric results reported in Chapter 5.

Between-Session Consistency and Test Re-Test Reliability

Since the median reaction time and mean prepotent accuracy variables were not normally distributed, related samples Wilcoxon Signed Rank tests and Spearman's rho correlation tests were conducted to test for convergence. Results were consistent with the results of the paired *t*-tests reported in Chapter 5: median inhibitory reaction time: $Z = -2.676$, $p = .007$, median prepotent reaction time: $Z = -3.460$, $p < .001$, and mean prepotent accuracy: $Z = 1.577$, $p = .115$. Correlation results were also aligned with the results of Pearson's

correlations (reported in Chapter 5): median inhibitory reaction time: r_s (54) = .165, p = .111, *CI* = -.109, .394, median prepotent reaction time: r_s (54) = .287, p = .016, *CI* = .009, .534, mean prepotent accuracy: r_s (65) = .090, p = .470, *CI* = -.194, .339.

Group Performance Differences

Accuracy: Results of independent samples Mann-Whitney U tests indicated that there was no significant difference in mean inhibitory accuracy: Z = -1.162, p = .245, mean prepotent accuracy: Z = -.052, p = .958, and accuracy inhibitory score: Z = -1.098, p = .272 between groups. These results align with the parametric test results reported in Chapter 5.

Reaction Time: Results of independent samples Mann-Whitney U tests indicated that there was no significant difference between groups in median inhibitory reaction time: Z = -1.516, p = .129, however, there was a significant difference between groups in median prepotent reaction time: Z = -2.997, p = .003. These results partially align with the parametric test results reported in Chapter 5.

Individual Differences Analyses

Since the HHb difference variable for Channel 28 (time bins 1, 4 and 7) was not normally distributed, the non-parametric Spearman's rho correlation analysis was also conducted. Results were in convergence with the results of the parametric correlation reported in Chapter 5: r_s (40) = -.140, p = .375, *CI* = -.429, .194.

4. fNIRS Group-Level Results: Main Effect of Time

The results of the repeated measures ANOVA that investigated which channels showed a significant change in haemoglobin concentration from baseline across the block time course (main effect of time) are presented in **Table 8** (HbO_2), and **Table 9** (HHb).

Table 8. Appendix C. Main Effect of Time (HbO_2) in the 16-month Dataset.

	Left hemisphere			Right hemisphere		
	Channel	*F*	*p*	Channel	*F*	*p*
Intraparietal Sulcus	1	2.459	.084	7	4.981	**.007***
	2	2.681	.058	8	.518	.640
	4	3.693	**.019***			
	6	.368	.735			
Prefrontal Cortex	13	.517	.661	20	.766	.472
	14	4.897	**.007***	21	5.888	**.003***
	16	2.642	.068	23	3.367	**.035**
	17	13.292	**<.001***	24	24.795	**<.001***
	18	15.754	**<.001***	25	18.439	**<.001***
	19	13.232	**<.001***	26	18.025	**<.001***
	27	.188	.846	31	1.194	.311
	28	3.762	**.015***	32		
	29	1.772	.168	33		
	35	1.018	.376	37	1.730	.180
	36	2.130	.114	38	.308	.804
	39	7.696	**<.001***	41	2.642	.059
	40	6.958	**<.001***	42	4.981	**.005***
	43	6.529	**<.001***	45	2.813	**.048**
	44	9.078	**<.001***	46	7.153	**<.001***

Note. Statistically significant results are highlighted in bold. * = significant at $p < .05$, corrected for 84 comparisons (or 12 comparisons for confirmatory analyses; Channels 25, 26, 32 and 33).

Table 9. Appendix C. Main Effect of Time (HHb) in the 16-month Dataset.

	Left hemisphere			Right hemisphere		
	Channel	*F*	*p*	Channel	*F*	*p*
Intraparietal Sulcus	1	1.904	.146	7	1.754	.169
	2	.855	.427	8	1.614	.199
	4	3.715	**.024**			
	6	3.327	**.030**			
Prefrontal Cortex	13	1.260	.291	20	1.575	.201
	14	1.349	.261	21	4.685	**.006***
	16	1.484	.229	23	3.018	**.041**
	17	5.320	**<.001***	24	12.480	**<.001***
	18	8.959	**<.001***	25	15.672	**<.001***
	19	10.989	**<.001***	26	15.028	**<.001***
	27	.744	.504	31	1.328	.267
	28	7.177	**<.001***	32	9.998	**<.001***
	29	3.418	**.026**	33	5.075	**.003***
	35	1.757	.166	37	1.872	.152
	36	5.196	**.003***	38	1.861	.163
	39	4.936	**.008***	41	8.469	**<.001***
	40	5.128	**.006***	42	6.926	**<.001***

	43	3.519	**.033**	45	4.453	**.005***
	44	1.724	.175	46	1.139	.334

Note. Statistically significant results are highlighted in bold. * = significant at $p < .05$, corrected for 84 comparisons (or 12 comparisons for confirmatory analyses; Channels 25, 26, 32 and 33).

5. Further Exploratory fNIRS Analyses

In the additional exploratory analyses that were conducted (but not pre-registered), three channels were identified as showing significant block type effects but did not show a significant main effect of time in either the HbO_2 or the HHb signal (**Table 10**). These are Channel 8 (right inferior parietal), Channel 20 (right IFG), and Channel 31 (right DLPFC). The HRF plots for these additional three channels can be found in **Figure 1**, **Figure 2**, and **Figure 3** below.

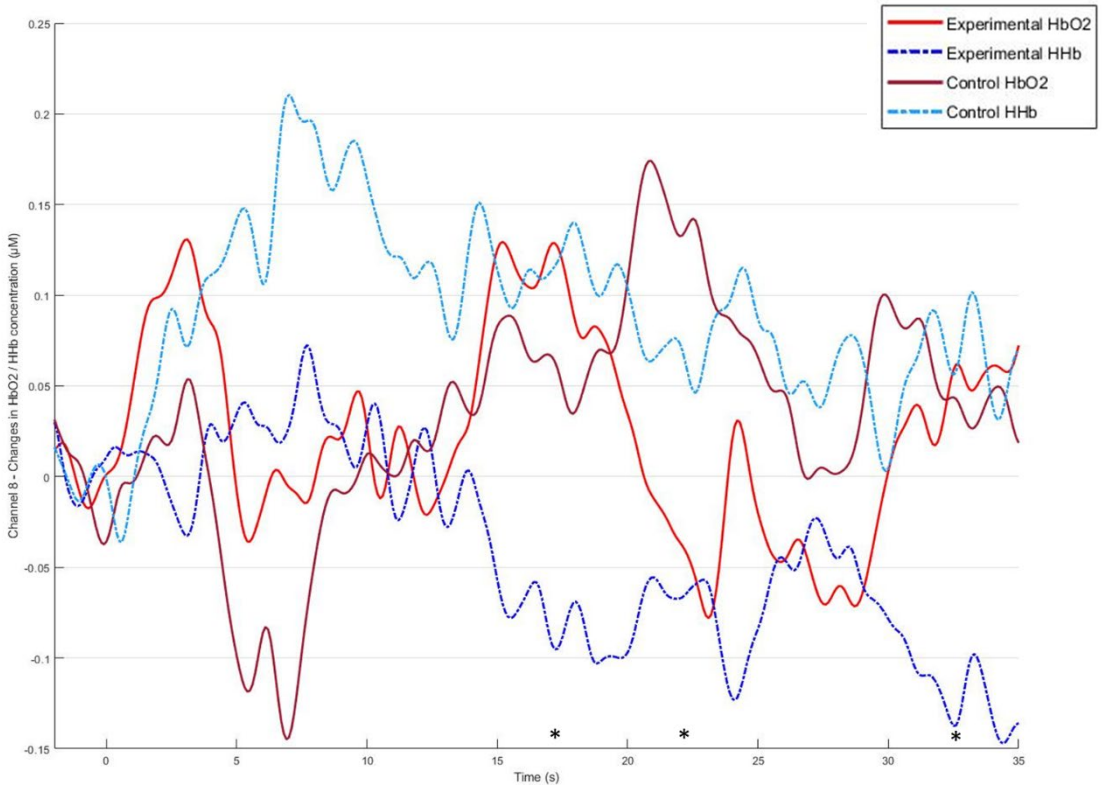
Table 10. Appendix C. Further Exploratory Analyses: Main Effect of Time (16-month Dataset).

Location	Hemisphere	Channel	Signal	*F*	*p*
Inferior parietal (angular gyrus)	Right	8	HbO_2	.518	.640
			HHb	1.614	.199
IFG	Right	20	HbO_2	.766	.472
			HHb	1.575	.201
DLPFC	Right	31	HbO_2	1.194	.311
			HHb	1.328	.267

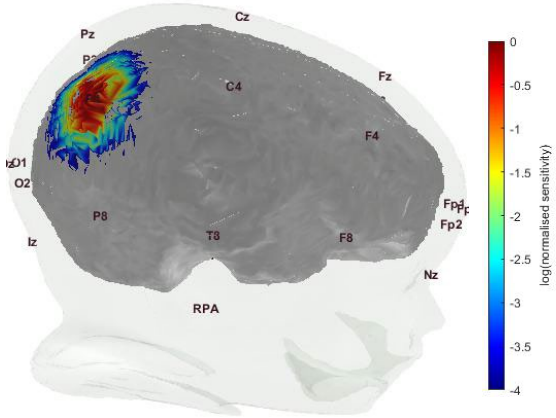
Note. IFG = inferior frontal gyrus, DLPFC = dorsolateral prefrontal cortex.

Figure 1. Appendix C. Haemodynamic Response Function for Channel 8 (Right Parietal) at 16-months.

a.



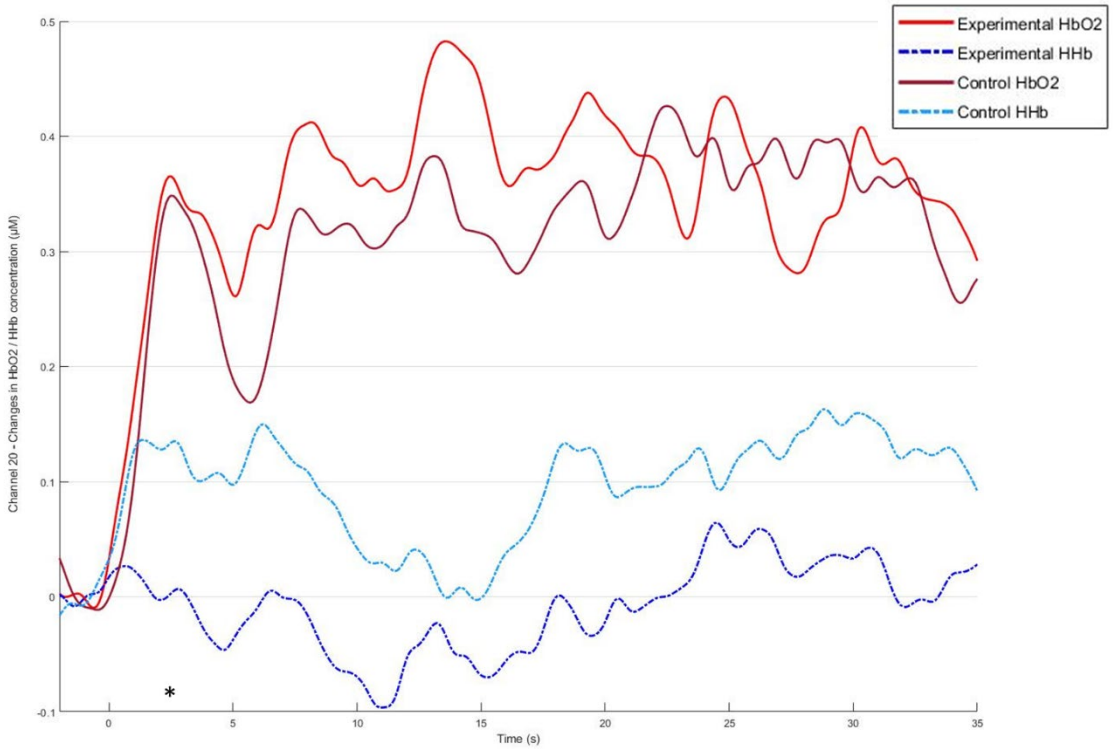
b.



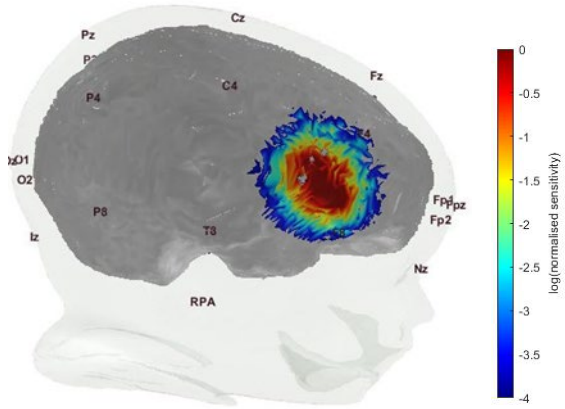
Note. a. Average haemodynamic response function for Channel 8 (*N* = 36) from -2 seconds (baseline) to 35 seconds of the block time course. Asterisks denote time bins where there is a **significant block type effect in the HHb signal** (the significant effects in both time bins survived the procedure for controlling the FDR).
b. Sensitivity profile illustrating the position of Channel 8 on the cortex and the channel sensitivity (heat map: red = more sensitive, blue = less sensitive).

Figure 2. Appendix C. Haemodynamic Response Function for Channel 20 (Right Inferior Frontal Gyrus, Triangular) at 16-months.

a.



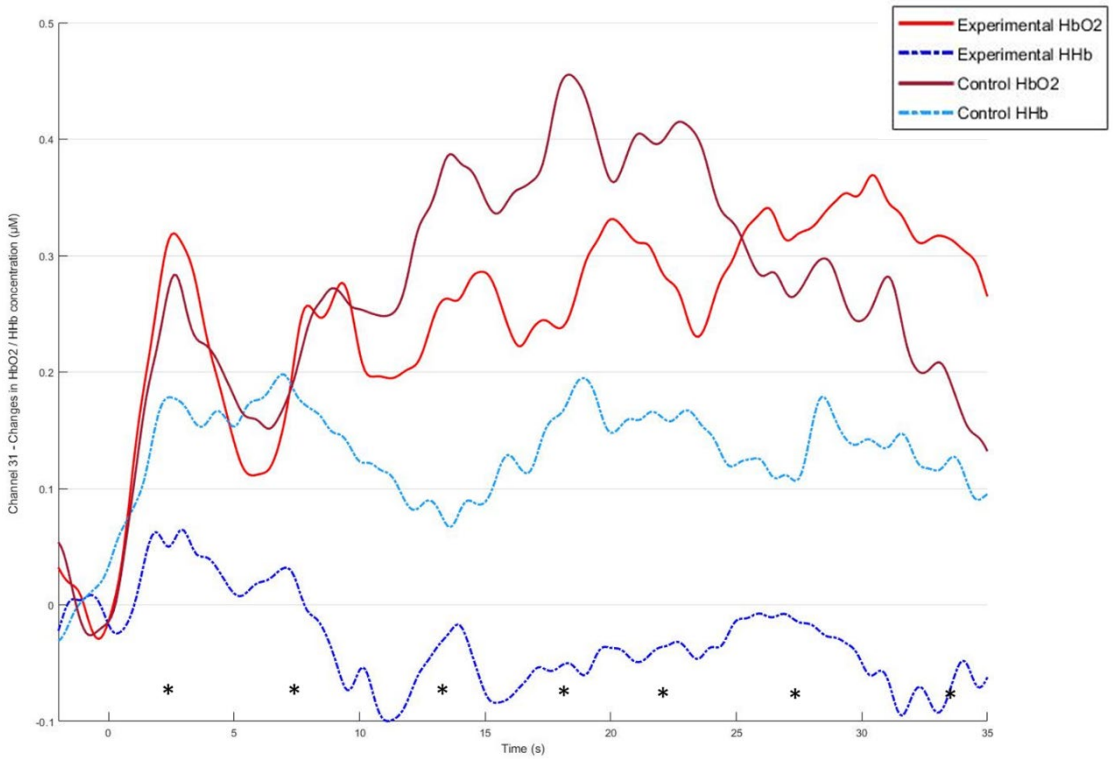
b.



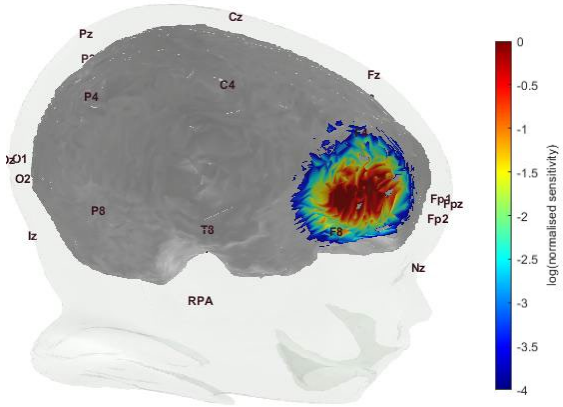
Note. a. Average haemodynamic response function for Channel 20 (*N* = 42) from -2 seconds (baseline) to 35 seconds of the block time course. Asterisks denote time bins where there is a **significant block type effect in the HHb signal** (the significant effects in time bin 1 survived the procedure for controlling the FDR).
b. Sensitivity profile illustrating the position of Channel 20 on the cortex and the channel sensitivity (heat map: red = more sensitive, blue = less sensitive).

Figure 3. Appendix C. Haemodynamic Response Function for Channel 31 (Right Inferior Frontal Gyrus, Orbital) at 16-months.

a.



b.



Note. a. Average haemodynamic response function for Channel 31 (*N* = 43) from -2 seconds (baseline) to 35 seconds of the block time course. Asterisks denote time bins where there is a **significant block type effect in the HHb signal** (the significant effects in all time bins survived the procedure for controlling the FDR).
b. Sensitivity profile illustrating the position of Channel 31 on the cortex and the channel sensitivity (heat map: red = more sensitive, blue = less sensitive).

Appendix D

Chapter 6: Behavioural and Neural Indices of Inhibitory Control from Infancy to Early Childhood

1. Author Contribution Statement for Chapter 6

The authors of the pre-registration (embargoed on OSF, but accessible here for this thesis) associated with Chapter 6 of this thesis are as follows: **Abigail Fiske (AF),** University of Oxford; Liam Collins-Jones (LCJ), University College London; Carina de Klerk (CdK), University of Essex; Karla Holmboe (KH), University of Oxford, University of Bristol

In addition to the authors named above, the following will be authors of the manuscript (Fiske et al. in prep) that reports on the data presented in this chapter: Alicia Mortimer (AM), University of Bath, University of Oxford; Alexandra Hendry (AHa), University of Oxford; Sylvia Gattas (SG), University of Oxford; Henrik Dvergsdal (HD), Nord University

The contributions of each author to this study are as follows:

- Conceptualisation – **AF,** KH
- Task design – KH (behavioural ECITT), KH, CdK, HD (blocked ECITT)
- Software programming - HD
- Analysis plan – **AF**, CdK, KH, LCJ
- Pre-registration – **AF**, LCJ, CdK, KH
- Data collection – **AF**, AM, SG
- Video coding and coding protocol development – **AF**, AM
- Data curation – **AF**, AM, KH, HD
- fNIRS Data processing and analysis – **AF**, AM, CdK
- Statistical analysis – **AF**, CdK, KH
- fNIRS image reconstruction, channel localisation, head modelling – LCJ
- Writing – original draft - **AF**
- Writing – reviewing and editing – **AF**, KH, CdK, GS, LCJ
- Supervision – KH, CdK, GS
- Project management and administration – KH
- Funding acquisition – KH, **AF**

2. Anatomical Labels of Channels in the fNIRS Probe

This work was completed by Dr Liam Collins-Jones for the pre-registered study (Fiske et al. in prep) associated with the data presented in Chapter 6 of the current thesis. **Table 11** below provides the anatomical label for each channel in the fNIRS probe in the 3½ year study. The changes in anatomical labels at 3½ years were minimal. At 3½ years, Channel 9 is labelled as covering the inferior parietal gyrus, whereas at 10- and 16-months this was labelled as the angular gyrus, and Channel 39 was labelled as covering the superior frontal gyrus (medial) at 3½ years but was labelled as covering the superior frontal gyrus (dorsolateral) at 10- and 16-months.

As stated in the pre-registration: *With this 3½ year dataset, for consistency across our longitudinal study, we decided to continue to generate the head model based on the averaged structural MRI data of a cohort of 12-month-old infants (Shi et al., 2011). The head model was scaled to the group mean head circumference measurement of the participants in the current sample at 3½ years. Whilst we recognise that there is substantial change in head size from 12-months to 3½ years, we feel that the consistency gained from keeping the atlas the same throughout the three studies is still advantageous and will make developmental comparisons more straightforward. This approach means that the channel localisation remains relatively consistent across studies, making it easier to investigate change in activation over time in this longitudinal dataset. Further, we have struggled to find an atlas that has suitable parcellation for 3½-year-olds, and we deem that it would not be ideal to use an adult atlas with this young population, as a preliminary assessment based on our probe and an adult atlas (AAL2; Rolls et al., 2015) indicated that a large proportion of channels would be located in different cortical areas. Upon careful inspection of these adult-based locations and images of our probe placement, we felt that they did not represent the channel locations accurately.*

Table 11. Appendix D. Anatomical Labels of Channels in the fNIRS Probe at 3½ years.

Channel	Hemisphere	Cortical Region
1	Left	'Inferior parietal gyrus (P2)'
2	Left	'Inferior parietal gyrus (P2)'
3	Left	'Superior parietal gyrus (P1)'
4	Left	'Inferior parietal gyrus (P2)'
5	Left	'Superior parietal gyrus (P1)'
6	Left	'Superior parietal gyrus (P1)'
7	Right	'Inferior parietal gyrus (P2)'
8	Right	'Angular gyrus (AG)'
9	Right	‘Inferior parietal gyrus (P2)'
10	Right	'Inferior parietal gyrus (P2)'
11	Right	'Superior parietal gyrus (P1)'
12	Right	'Superior parietal gyrus (P1)'
13	Left	'Inferior frontal gyrus, triangular (F3T)'

14	Left	'Inferior frontal gyrus, triangular (F3T)'
15	Left	'Middle frontal gyrus (F2)'
16	Left	'Inferior frontal gyrus, triangular (F3T)'
17	Left	'Middle frontal gyrus (F2)'
18	Left	'Middle frontal gyrus (F2)'
19	Left	'Middle frontal gyrus (F2)'
20	Right	'Inferior frontal gyrus, triangular (F3T)'
21	Right	'Middle frontal gyrus (F2)'
22	Right	'Middle frontal gyrus (F2)'
23	Right	Inferior frontal gyrus, triangular (F3T)'
24	Right	'Middle frontal gyrus (F2)'
25	Right	'Middle frontal gyrus (F2)'
26	Right	'Middle frontal gyrus (F2)'
27	Left	'Inferior frontal gyrus, orbital (F3O)'
28	Left	'Middle frontal gyrus (F2)'
29	Left	'Middle frontal gyrus, orbital (F2O)'
30	Left	'Middle frontal gyrus (F2)'
31	Right	'Inferior frontal gyrus, orbital (F3O)'
32	Right	'Middle frontal gyrus (F2)'
33	Right	'Middle frontal gyrus, orbital (F2O)'
34	Right	'Middle frontal gyrus (F2)'
35	Left	'Superior frontal gyrus, dorsolateral (F1)'
36	Left	'Superior frontal gyrus, dorsolateral (F1)'
37	Right	'Superior frontal gyrus, dorsolateral (F1)'
38	Right	'Superior frontal gyrus, dorsolateral (F1)'
39	Left	'Superior frontal gyrus, medial (F1M)'
40	Left	'Superior frontal gyrus, medial (F1M)'
41	Right	'Superior frontal gyrus, dorsolateral (F1)'
42	Right	'Superior frontal gyrus, medial (F1M)'
43	Left	'Superior frontal gyrus, dorsolateral (F1)'
44	Left	'Superior frontal gyrus, medial orbital (F1MO)'
45	Right	'Superior frontal gyrus, dorsolateral (F1)'
46	Right	'Superior frontal gyrus, orbital (F1O)'

Note. The anatomical labels for each channel were created using the infant automated anatomical labelling (AAL) atlas presented by Shi et al. (2011).

3. Parametric Test Assumptions

Each behavioural and fNIRS-related variable was tested for normality by examining the results of the Shapiro-Wilk test and the skewness (z-score) of the data; the results and conclusions of these tests are reported in **Table 12** below. Please see Appendix B3 for details about how these tests were conducted. Note that the sphericity of the fNIRS data was

tested using Mauchly's test of sphericity and data from all but one channel (Channel 9) did not meet the sphericity assumption. Therefore, the Greenhouse-Geisser degrees of freedom and *p*-values were reported to account for the lack of sphericity in all channels.

Table 12. Appendix D. Normality Tests for the 3½ year Dataset.

	Variable	*N*	Shapiro-Wilk (*p*)	Skew (z)	Conclusion
Behavioural ECITT (Session 1)	Mean inhibitory accuracy	113	<.001	-3.49	**Not normally distributed, skew not acceptable**
	Mean prepotent accuracy	113	<.001	-7.79	**Not normally distributed, skew not acceptable**
	Accuracy inhibitory score	113	<.001	-3.93	**Not normally distributed, skew not acceptable**
	Median inhibitory reaction time	113	<.001	6.77	**Not normally distributed, skew not acceptable**
	Median prepotent reaction time	113	<.001	5.86	**Not normally distributed, skew not acceptable**
Blocked ECITT (Session 2)	Mean inhibitory accuracy	100	<.001	-3.22	Not normally distributed, acceptable skew
	Mean prepotent accuracy	100	<.001	-33.54	**Not normally distributed, skew not acceptable**
	Accuracy inhibitory score	100	<.001	-3.41	**Not normally distributed, skew not acceptable**
	Median inhibitory reaction time	100	<.001	6.16	**Not normally distributed, skew not acceptable**
	Median prepotent reaction time	100	<.001	4.62	**Not normally distributed, skew not acceptable**
Individual Differences	Channel 7 HHb Difference Bin 5	36	.236	1.16	Normally distributed, acceptable skew
	Channel 8 HHb Difference Bins 4 - 5	33	<.001	3.98	**Not normally distributed, skew not acceptable**
	Channel 18 HbO_2 Difference Bins 3 - 4	50	<.001	-9.27	**Not normally distributed, skew not acceptable**
	Channel 29 HHb Difference Bin 2	57	<.001	-4.40	**Not normally distributed, skew not acceptable**
	Channel 31 HbO_2 Difference Bins 1 - 2	52	.217	-1.20	Normally distributed, acceptable skew
	Channel 31 HHb Difference Bins 3 - 5	52	.501	1.50	Normally distributed, acceptable skew
	Channel 43 HHb Difference Bins 1 – 3	41	.924	0.31	Normally distributed, acceptable skew
	Channel 45 HbO_2 Difference Bins 1 – 2	47	.704	-0.42	Normally distributed, acceptable skew

3.1. Results of Non-Parametric Tests

ECITT Condition Effects

H1 & H2: Results of non-parametric Wilcoxon signed rank tests supported the hypotheses that participants would be significantly more accurate on prepotent trials than on inhibitory trials (H1): $Z = 6.993$, $p < .001$, and that participants would respond significantly faster on

correct prepotent trials than on correct inhibitory trials (H2): Z = -8.431, p <.001. Results aligned with the results of the parametric paired *t*-tests reported in Chapter 6.

Behavioural Development from Infancy to Early Childhood

Accuracy: Results of non-parametric related-samples Wilcoxon Signed Rank tests revealed that there was a significant difference in accuracy (mean prepotent accuracy, mean inhibitory accuracy, accuracy inhibitory score) from 10-months to 3½ years (H6a), and from 16-months to 3½ years (H6b), whereby participants were significantly more accurate at 3½ years than at 10- or 16-months. Results are reported in **Table 17** below and are in alignment with the parametric tests.

Reaction Time: Results of non-parametric related-samples Wilcoxon Signed Rank tests revealed that there was a significant difference in reaction time from 16-months to 3½ years (H6b), whereby participants responded significantly faster at 3½ years than at 16-months. Results are reported in **Table 13** below and are in alignment with the parametric tests).

Table 13. Appendix D. Non-Parametric Longitudinal Analyses at 3½ years (ECITT).

	10-months and 3½ years		**16-months and 3½ years**	
	N	Statistic	N	Statistic
Mean inhibitory accuracy	79	Z = 4.996, p <.001	44	Z = 3.206, p = .001
Mean prepotent accuracy	79	Z = 6.085, p <.001	44	Z = 4.694, p < .001
Accuracy inhibitory	78	Z = 3.785, p <.001	44	Z = 2.544, p = .011
Median inhibitory reaction time	-	-	42	Z = -2.895, p = .004
Median prepotent reaction time	-	-	42	Z = -5.133, p < .001

Note. All results remained significant following the procedure for controlling the FDR (N = 8 comparisons).

H7: Four separate Spearman's correlational analyses were conducted to examine whether there is a significant association between performance on the blocked ECITT at 10-months and 3½ years (H7a) and at 16-months and 3½ years (H7b). Results are reported in **Table 14** and are in alignment with the results of the parametric tests.

Table 14. Appendix D. Performance on the ECITT at 3½ years: Longitudinal Associations.

	Statistic
Accuracy Inhibitory Score (10-months and 3½ years)	r_s (76) = -.037, p = .375
Accuracy Inhibitory Score (16-months and 3½ years)	r_s (40) = -.222, p = .082
Median Prepotent Reaction Time	r_s (40) = .015, p = .463
Median Inhibitory Reaction Time	r_s (40) = .224, p = .086

Additional Exploratory (Not Pre-Registered) Longitudinal Analyses

It was pre-registered that two separate linear mixed models would be conducted to investigate the change in accuracy performance on the ECITT across assessment points (results are reported in Chapter 6 of this thesis). Model 1 examined change from 10-months to 3½ years, and Model 2 examined change from 16-months to 3½ years. As predicted, the results indicated that there was a significant main effect of age in both models (such that participants were significantly more accurate at 3½ years than at 10- or 16-months of age) and that there was a significant main effect of trial type in both models (such that participants were significantly more accurate on prepotent trials than on inhibitory trials). There was also a significant interaction effect in both models, whereby there was a larger improvement in inhibitory accuracy than in prepotent accuracy between 10 months and 3½ years and between 16-months and 3½ years.

An additional exploratory (not pre-registered) 3 × 2 linear mixed model was conducted with the accuracy data from the ECITT as the dependent variable, and assessment point (10-months, 16-months and 3 ½ years) and trial type (prepotent, inhibitory) as the within-subject factors. Estimated marginal means are reported in **Table 15** below. This was done to establish a full picture of accuracy development across infancy and early childhood. The results of the model suggest that there was a significant main effect of assessment point: F (2, 239.184) = 62.988, p< .001, Cohen's f = 0.72. Results of Bonferroni-corrected post-hoc tests revealed that there was no significant difference between the estimated marginal mean for accuracy at 10-months and 16-months: mean difference = -.005, SE = .023, df = 181.518, p = 1.00, CI = -.050, .061. However, there was a significant improvement from 10-months to 3½ years: mean difference = .165, SE = .017, df = 251.907, p<.001, CI = .125, .206, and from 16-months to 3 ½ years: mean difference = .170, SE = .021, df = 143.137, p <.001, CI = .119, .222.

A significant main effect of trial type was also found F (1, 243.369) = 351.845, p <.001, Cohen's f = 1.20, such that accuracy was significantly higher on prepotent trials than on inhibitory trials, as would be expected. Finally, there was a significant assessment point × trial type interaction: F (2, 239.184) = 22.112, p <.001, Cohen's f = 0.42. This suggests that there was a larger accuracy improvement on inhibitory trials than on prepotent trials across assessment points.

Table 15. Appendix D. Estimated Marginal Means: Accuracy Improvement from Infancy to Early Childhood.

		Estimated marginal mean	Standard error	Degrees of Freedom	Confidence interval
Trial Type	Inhibitory	.632	.016	213.409	.600, .664
	Prepotent	.946	.004	199.159	.937, .954
Age	10-months	.735	.013	148.395	.709, .762
	16-months	.730	.019	91.636	.693, .767
	3½ years	.901	.010	106.763	.880, .921
Interaction	Inhibitory 10-months	.549	.026	127	.497, .600
	Prepotent 10-months	.922	.008	127	.907, .937
	Inhibitory 16-months	.536	.036	80	.465, .608
	Prepotent 16-months	.924	.010	80	.905, .943
	Inhibitory 3½ years	.810	.020	99	.771, .999
	Prepotent 3½ years	.991	.004	99	.983, .999

Between-Session Consistency and Test Re-Test Reliability

H4: Results of non-parametric related-samples Wilcoxon Signed Rank tests revealed that there was a significant difference in prepotent accuracy between sessions, whereby participants were significantly more accurate in Session 2 (M = .991, SD = .039) than in Session 1 (M = .973, SD = .036): Z = 5.598, p < .001. However, there was no significant difference in inhibitory accuracy between sessions: Z = 1.845, p = .065. There was also no significant difference in accuracy inhibitory score between sessions: Z = 1.148, p = .251.

For the reaction time variables, results of non-parametric related-samples Wilcoxon Signed Rank tests revealed that there was a significant difference in prepotent reaction time between sessions, whereby participants were significantly faster in Session 2 (M = 1024 ms, SD = 280 ms) than in Session 1 (M = 1496 ms, SD = 437 ms): Z = -8.259, p < .001. Similarly, there was a significant difference in inhibitory reaction time between sessions, whereby participants were significantly faster in Session 2 (M = 1378 ms, SD = 328 ms) than in Session 1 (M = 1757 ms, SD = 489 ms): Z = -7.342, p < .001.

Overall, these results suggest that participants responded significantly faster on both trial types in Session 2 than in Session 1 and that participants were significantly more accurate on prepotent trials (but not inhibitory trials) in Session 2 than in Session 1.

To establish test re-test reliability, five confirmatory correlational analyses were conducted on data from the behavioural ECITT (Session 1) and the blocked ECITT (Session 2), results are reported in **Table 16** below and support the hypotheses (H5). However, there is some convergence from the results of parametric correlation analyses reported in Chapter 6.

Table 16. Appendix D. ECITT Test Re-test Reliability at 3½ years.

	Spearman's correlation coefficient	*p*	Confidence interval
Mean inhibitory accuracy	*r* (94) = .452	**<.001**	.254, .623
Mean prepotent accuracy	*r* (94) = .217	**.017**	-.012, .413
Accuracy inhibitory	*r* (94) = .428	**<.001**	.250, .592
Median inhibitory reaction time	*r* (94) = .552	**<.001**	.378, .689
Median prepotent reaction time	*r* (94) = .174	**.042**	-.004, .345

Note. Statistically significant results are highlighted in bold. All results remained significant following the procedure for controlling the FDR (*N* = 5 comparisons).

ECITT Group Performance Differences

H3a: Results of non-parametric Mann-Whitney U tests revealed that there was no significant difference in inhibitory accuracy between groups (those with fNIRS data: *N* = 61 and those without fNIRS data: *N* = 39): *Z* = .196, *p* = .845, however does suggest that participants who contributed valid fNIRS data were significantly more accurate on prepotent trials (mean rank = 53.61) than those who did not contribute valid fNIRS data (mean rank = 45.64): *Z* = 1.999, *p* = .046. This does not align with the results of parametric tests reported in Chapter 6.

H3b: Results of non-parametric Mann-Whitney U tests revealed that there was no significant difference in median prepotent reaction time between groups: *Z* = -.671, *p* = .502, however there was evidence to suggest that participants who contributed valid fNIRS data were significantly faster at responding on inhibitory trials (mean rank = 44.93) than those without valid fNIRS data (mean rank = 59.21): *Z* = -2.399, *p* = .016. This aligns with parametric test results reported in Chapter 6.

Individual Differences Analyses

In line with the pre-registration, exploratory correlational analyses were conducted to investigate whether individual differences in neural activation in specific channels (showing significant block type effects across the identified time-bins) were associated with individual performance differences in the accuracy inhibitory score. Results of Spearman's correlational analyses (**Table 17**) revealed that there were no significant associations between performance on the ECITT (accuracy inhibitory score) and the haemoglobin

difference variables. These results were in convergence with the results of the parametric Pearson's correlational analyses reported in Chapter 6.

Table 17. Appendix D. Individual Differences Analyses at 3½ years.

Location	Hemisphere	Channel	Signal	Time Bins	Statistic
Inferior parietal	Right	7	HHb	5	r_s (35) = -.088, p = .612, *CI* = -.452, .266
		8*	HHb	4 – 5	r_s (32) = -.198, p = .268, *CI* = -.509, .153
IFG	Right	**31***	HbO_2	1 – 2	r_s (51) = .006, p = .968, *CI* = -.291, .310
			HHb	3 – 5	r_s (51) = .067, p = .636, *CI* = -.206, .344
DLPFC	Left	18	HbO_2	3 – 4	r_s (49) = -.125, p = .388, *CI* = -.411, .149
		43	HHb	1 – 3	r_s (40) = -.054, p = .738, *CI* = -.359, .246
	Right	45	HbO_2	1 – 2	r_s (46) = -.160, p = .283, *CI* = -.453, .149
OFC	Left	**29***	HHb	2	r_s (56) = -.146, p = .279, *CI* = -.373, .128

Note. IFG = inferior frontal gyrus, DLPFC = dorsolateral prefrontal cortex, OFC = orbital frontal cortex.

4. fNIRS Group-Level Results

Table 18 and **Table 19** display the results of repeated measures ANOVAs for channels showing a significant main effect of time (a significant increase in HbO_2 / decrease in HHb from baseline).

Table 18. Appendix D. Main Effect of Time (HbO2) in the 3½ year Dataset.

		Left hemisphere			**Right hemisphere**	
	Channel	*F*	*p*	Channel	*F*	*p*
IPS	1	8.228	**<.001***	7	7.273	**.001***
	4	1.553	.217	8	2.497	.085
Prefrontal Cortex	13	3.797	**.028***	20	.990	.375
	14	3.693	**.037**	21	3.305	**.037**
	16	8.942	**<.001***	23	6.924	**.002***
	17	27.417	**<.001***	25	26.162	**<.001***
	18	14.582	**<.001***	26	36.350	**<.001***
	19	26.901	**<.001***	31	16.935	**<.001***
	27	13.568	**<.001***	32	45.233	**<.001***
	28	18.153	**<.001***	33	30.806	**<.001***
	29	9.767	**<.001***	37	23.455	**<.001***
	35	3.325	**.040**	38	44.366	**<.001***
	36	3.129	.053	41	21.858	**<.001***

	39	.679	.509	42	14.578	**<.001***
	40	.678	.498	45	14.407	**<.001***
	43	.185	.828	46	4.285	**.023***
	44	.784	.463			

Note. Statistically significant results are highlighted in bold. * = remained significant following the procedure for controlling the FDR (*N* = 16 comparisons; 8 confirmatory channels × 2 chromophores) (*N* = 50 comparisons, 25 exploratory channels × 2 chromophores).

Table 19. Appendix D. Main Effect of Time (HHb) in the 3½ year Dataset.

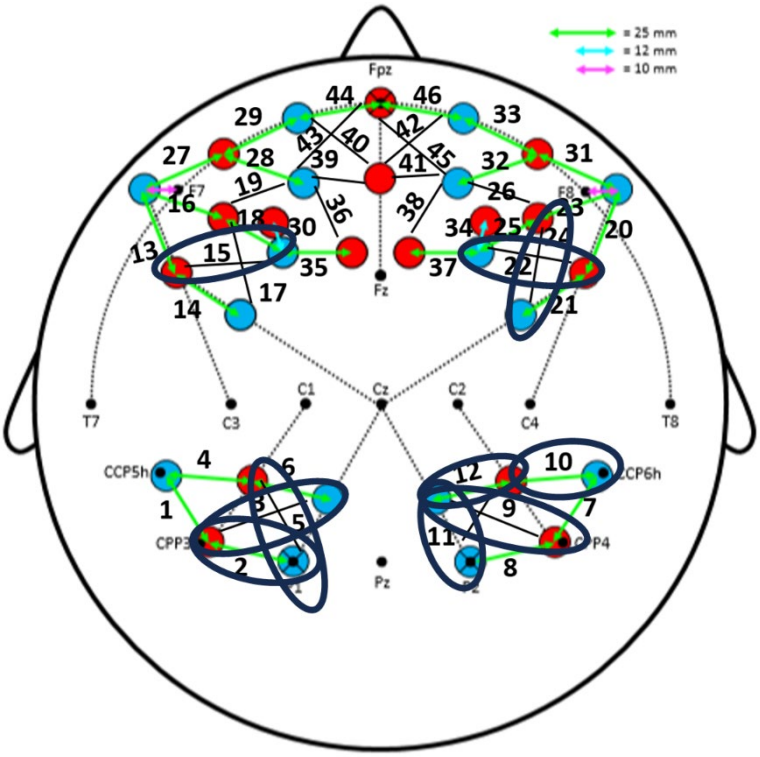
		Left hemisphere			**Right hemisphere**	
	Channel	*F*	*p*	Channel	*F*	*p*
IPS	1	.791	.477	7	1.099	.342
	4	.961	.381	8	1.533	.220
Prefrontal Cortex	13	5.421	**.006***	20	.542	.614
	14	5.323	**.007***	21	2.402	.099
	16	2.597	.089	23	.878	.422
	17	4.795	**.011***	25	7.359	**.001***
	18	1.743	.171	26	11.470	**<.001***
	19	6.863	**.001***	31	4.659	**.010***
	27	4.284	**.021***	32	19.882	**<.001***
	28	22.733	**<.001***	33	13.569	**<.001***
	29	9.059	**<.001***	37	3.726	**.029***
	35	2.866	.068	38	6.574	**.003***
	36	4.840	**.013***	41	5.533	**.011***
	39	4.266	**.024***	42	10.605	**<.001***
	40	5.848	**.003***	45	16.935	**<.001***
	43	7.245	**<.001***	46	12.303	**<.001***
	44	7.762	**<.001***			

Note. Statistically significant results are highlighted in bold. * = remained significant following the procedure for controlling the FDR (*N* = 16 comparisons; 8 confirmatory channels × 2 chromophores) (*N* = 50 comparisons, 25 exploratory channels × 2 chromophores).

Excluded Channels

It was found during pre-processing of the fNIRS data that there were 10 channels for which less than 50% of participants contributed data (bilateral parietal: Channels 2, 3, 5, 9, 10, 11, 12, and bilateral middle frontal gyrus: 15, 22, and 24). These channels were excluded from the analysis. **Figure 4** highlights where these channels were located on the fNIRS probe.

Figure 4. Appendix D. Excluded Channels Displayed on the fNIRS Probe.



Appendix E

Chapter 7: 'Hot' and 'Cool' Inhibitory Control in Infancy and Early Childhood: Longitudinal Associations and Contributions to Pre-Academic Outcomes

1. Full Task Protocol for Treasure Delay (3½ years)

Children were told that they were going to play a game where they could win some treasure and were introduced to a pirate puppet named 'Perry', who they were going to play with. They were told that Perry loves treasure and is a greedy pirate who wants to keep all the treasure for himself. Two identical containers were then placed on the table in front of the child, one containing gold pirate-themed pretend coins, and the other containing shiny red pretend jewels. The experimenter asked the children: "Do you want to play with the gold pirate coins or the ruby red gems today?" and the child was expected to choose which treasure they most liked (*N* = 39 chose the gold coins and *N* = 55 chose the ruby red gems). Children responded by either pointing to the container, verbally specifying which treasure they wanted or touching the preferred treasure. Once the child had chosen, the two containers were removed from the table and replaced with the two container lids, and two treasure chests. The experimenter told the child that when they win treasure, they should put it in their treasure chest (the experimenter opened the treasure chest and positioned it to the right-hand side of the child) and that when Perry wins treasure, he will put it in his treasure chest (which was opened and positioned to the right of the experimenter).

The experimenter then placed the treasure (either the coins or the gems) onto the lids that remained on the table. The treasure was always positioned in the same layout: one lid contained five pieces of treasure (laid out like the five dots on dice) and the other contained two pieces of treasure (laid out like the two dots on dice). Note that the amounts chosen were not specifically chosen for numerical purposes but were selected such that it was obvious (without counting) that one tray had more treasure than the other. The experimenter told the child that in this game, they should try and get as much treasure as they can in their treasure chest, and if they have more treasure than Perry at the end of the game, then they will win a special prize, but if Perry has more treasure at the end, then he will win the prize. See **Figure 5** for an image showing the task set-up and apparatus.

The first trial was a practice trial, where the treasure was laid out on the trays in front of the child (five pieces of treasure on one tray, two pieces on the other). The position of the five

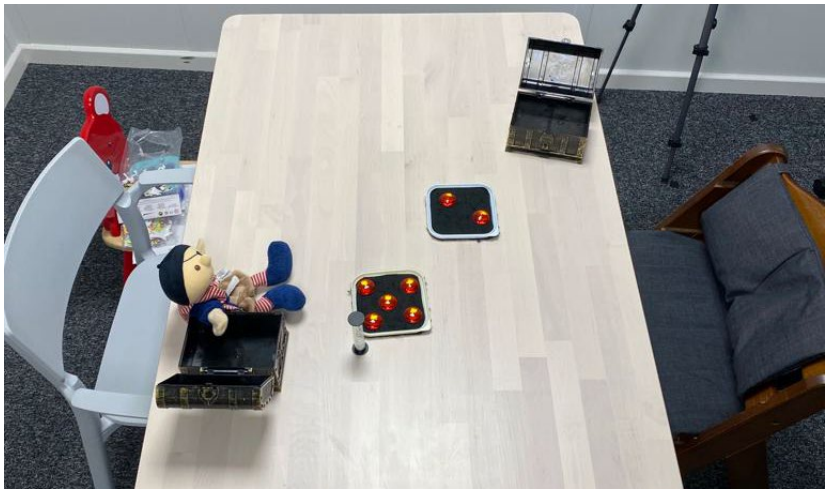
and two amounts on the first trial were counterbalanced between participants, such that for half of the participants the tray of five was positioned on the child's left, and for the remaining half it was positioned on the child's right. The experimenter reminded the child of the rules of the game (i.e., to win, they need to have the most treasure) and asked the child which one they wanted, encouraging the child to choose between the two trays by either replying verbally or pointing. It was expected that the child would choose the tray with five pieces of treasure on it, as this would be conducive to winning the game. If the child chose the tray of five, the experimenter would say "That's right – I would choose this one too because it has lots of treasure on it and you need lots of treasure to win the game. But, if you want the one with lots of treasure, you have to wait before you can put it in your treasure chest". The experimenter then introduced a small 30-second sand-timer to the child, asked if they had seen one before and explained to the child that we can watch the sand fall to the bottom, and when it's finished, they can put their treasure in their treasure chest. The experimenter then encouraged the child by saying "Let's practice" and turning over the sand timer. During this time, the experimenter would look away from the child (either at the floor or at the sand timer), remaining still and trying to avoid any social interaction with the child or the parent. No instructions were given to the child about how to behave during the waiting period. When the timer had finished, the experimenter told the child that they could now put their treasure in their treasure chest. If the child chose the smaller tray of treasure on the practice trial, the experimenter reminded them that to win the game, they must try and get as much treasure as they can and showed the child that the tray with five pieces of treasure on would help them win. Then, the process as described above would occur such that all children experienced the 30 seconds of waiting on the practice trial.

After the practice trial, there were three experimental trials. The position of the treasure (large or small tray) was swapped each time to ensure the child was not choosing due to a side bias. Before each experimenter trial, the experimenter reminded the child of the rules of the game and then asked the child "Would you like this treasure now (pushing the tray of two towards the child) or would you like to wait for this treasure (points at the tray of five)". Children were scored on whether they chose the small tray (0) or large tray (1) on each trial (total possible score of 3). Behaviour was scored during the session by a second experimenter observing the session on a laptop from behind a screen in the same room.

After the three experimental trials had been conducted, an additional trial was completed as a "preference check" to confirm whether or not the child understood the aim of the task (i.e., to get the most treasure). In this trial, the experimenter explained to the child "This time, we don't need to wait any more. I'm going to put the sand timer away" and removed the sand timer from the table and placed it out of sight of the child. The experimenter asks the child

again which tray of treasure they would like and allows them to put the treasure in their treasure chest. If the child chose the tray with five pieces of treasure, it could be assumed that they understood the aim of the game. If the child chose the tray with two pieces of treasure, it could be assumed that they did not understand the aim of the game. As such, data from children who did not pass the preference check were not included in the current study (N = 10 participants).

Figure 5. Appendix E. Treasure Delay Task.



Note. This image demonstrates the setup and apparatus used in the Treasure Delay task.

2. Parametric Test Assumptions

Variables were tested for normality by examining the results of the Shapiro-Wilk test and the skewness (z-score) of the data; results and conclusions are reported in **Table 20**. If the Shapiro-Wilk *p*-value is > .005, data are normally distributed, but if p < .005, data may deviate from a normal distribution. According to Kim (2013), for samples with > 50 and < 300 participants, a z-scored skew > 3.29 would suggest the sample distribution is not normal. Where variables are not normally distributed and are skewed beyond an acceptable level, non-parametric tests will be conducted alongside parametric tests to check for convergence.

Table 20. Appendix E. Normality Tests.

	Variable	*N*	Shapiro-Wilk (*p*)	Skew (z)	Conclusion
10-months	Toy Prohibition Latency	148	<.001	15.879	**Not normally distributed, skew not acceptable**
	Touchscreen Prohibition Latency	148	<.001	18.678	**Not normally distributed, skew not acceptable**
	'Hot' Inhibitory Control	148	<.001	15.065	**Not normally distributed, skew not acceptable**
	ECITT Accuracy Inhibitory Score	130	<.001	-0.528	Not normally distributed, acceptable skew
16-months	Toy Prohibition Latency	80	<.001	2.301	Not normally distributed, acceptable skew
	Touchscreen Prohibition Latency	81	<.001	3.352	Not normally distributed, acceptable skew
	'Hot' Inhibitory Control	80	<.001	2.662	Not normally distributed, acceptable skew
	ECITT Accuracy Inhibitory Score	65	.001	-0.111	Not normally distributed, acceptable skew
3½ years	Treasure Delay	84	<.001	-4.806	**Not normally distributed, skew not acceptable**
	Gift Delay	122	<.001	-7.525	**Not normally distributed, skew not acceptable**
	Dinky Toys	97	<.001	0.335	Not normally distributed, acceptable skew
	Hot Inhibitory Control (Gift & Dinky Toys)	97	<.001	-0.600	Not normally distributed, acceptable skew
	ECITT Accuracy Inhibitory Score	119	<.001	-3.739	**Not normally distributed, skew not acceptable**
	Fish & Sharks (Go/No-Go) Accuracy Inhibitory Score	103	<.001	-7.748	**Not normally distributed, skew not acceptable**
	Fish & Sharks (Go/No-Go) Impulse Control Score	103	<.001	-4.013	**Not normally distributed, skew not acceptable**
	EYT Numbers	123	.466	1.367	Normally distributed, acceptable skew
	WPPSI VCI	89	.285	-0.976	Normally distributed, acceptable skew

Note. The ECITT accuracy inhibitory score is from the behavioural ECITT completed in Session 1. EYT = Early Years Toolbox. WPPSI VCI = Weschler Preschool Primary Scales of Intelligence, Verbal Comprehension Index.

2.1. Results of Non-Parametric Tests

Change in Group-Level Performance

Although not pre-registered, it is important to consider how performance at the group level changed across assessment points when the same tasks were used. Exploratory (two-tailed) paired samples *t*-tests were conducted to examine change in performance on the 'hot' inhibitory control tasks from 10- to 16-months, and on the ECITT from infancy to 3½ years. Results (**Table 21**) are aligned with the non-parametric test results reported in Chapter 7.

Table 21. Appendix E. Group-Level Performance Change.

Tasks	Statistic
Toy Prohibition (10- and 16-months)	t (75) = -4.525, p <.001, d = -.519
Touchscreen Prohibition (10- and 16-months)	t (76) = -4.730, p < .001, d = -.539
ECITT (10-months to 3½ years)	t (79) = -5.208, p <.001, d = -.582
ECITT (16-months to 3½ years)	t (44) = -5.128, p <.001, d = -.764

Within-Age Associations – Inhibitory Control

Results of within-age Spearman's correlational analyses are reported in **Table 22** below. Since the 'hot' inhibitory control tasks were significantly correlated at both 10- and 16-months, an average 'hot inhibitory control' score was calculated for each assessment point and was used in further analyses. 'Cool' – 'Hot' exploratory correlational analyses (not pre-registered) were also conducted using the Go / No-Go 'Impulse Control Score' and no significant results were found (**Table 23**). Results are consistent with those reported in Chapter 7.

Table 22. Appendix E. Within-Age 'Hot' and 'Cool' Inhibitory Control Associations.

Type	Tasks	Assessment Point	Statistic
Infancy Within-Age Associations (H1, H2)			
Hot	Touchscreen Prohibition and Toy Prohibition	16-months	**r_s (78) = .475, p < .001***, *CI* = .261, .648**
Cool and Hot	ECITT and Hot Inhibitory Control	16-months	r_s (62) = .015, p = .907, *CI* = -.217, .235[a]
Early Childhood Within-Age Associations (H3, H4, H5)			
Cool and Hot	ECITT and Treasure Delay	3½ years	r_s (81) = -.179, p = .106, *CI* = -.388, .049[a]
	ECITT and Gift Delay	3½ years	**r_s (115) = .221, p = .017*, *CI* = .050, .383[a, b]**
	ECITT and Dinky Toys	3½ years	r_s (94) = -.031, p = .765, *CI* = -.258, .184[a]
	Go / No-Go and Treasure Delay	3½ years	r_s (67) = .048, p = .698, *CI* = -.201, .273[a]
	Go / No-Go and Gift Delay	3½ years	r_s (101) = .052, p = .604, *CI* = -.167, .250[a]
	Go / No-Go and Dinky Toys	3½ years	r_s (80) = .117, p = .294, *CI* = -.091, .314[a]

Note: *** p < .001, * p < .05. Statistically significant results are highlighted in bold. [a] Two-tailed correlational analysis. [b] Did not survive the procedure for controlling the FDR (N = 7 comparisons).

Table 23. Appendix E. Go / No-Go Impulse Control: Within-Age 'Hot' and 'Cool' Inhibitory Control Associations.

Tasks	Assessment Point	Statistic
Go / No-Go and ECITT	3½ years	r_s (97) = .231, p = .021, *CI* = .036, .400
Go / No-Go and Treasure Delay	3½ years	r_s (67) = .137, p = .263, *CI* = -.148, .391
		r_b (67) = .107, p = .264, *CI* = -.125, .316
Go / No-Go and Gift Delay	3½ years	r_s (101) = .158, p = .111, *CI* = -.036, .350
		r_b (101) = .121, p = .114, *CI* = -.028, .275
Go / No-Go and Dinky Toys	3½ years	r_s (80) = .156, p = .162, *CI* = -.065, .376
		r_b (80) = .118, p = .159, *CI* = =.052, .293

Longitudinal Associations (Inhibitory Control)

Results of longitudinal Spearman's correlational analyses (H6 – H9) are reported in **Table 24** below. Results are consistent with those reported in Chapter 7.

Table 24. Appendix E. Longitudinal 'Hot' and 'Cool' Inhibitory Control Associations.

Type	Tasks	Assessment Point	Statistic
Hot	'Hot' Inhibitory Control and Treasure Delay	10-months and 3½ years	r_s (80) = .006, p = .956, *CI* = -.212, .234[a]
		16-months and 3½ years	r_s (43) = -.117, p = .223, *CI* = -.399, .209 [a]
Hot	'Hot' Inhibitory Control and Gift Delay	10-months and 3½ years	r_s (94) = .125, p = .224, *CI* = -.066, .328 [a]
		16-months and 3½ years	r_s (52) = -.192, p = .082, *CI* = -.488, .131 [a]
Hot	'Hot' Inhibitory Control and Dinky Toys	10-months and 3½ years	r_s (81) = .061, p = .583, *CI* = -.147, .282 [a]
		16-months and 3½ years	r_s (47) = .089, p = .272, *CI* = -.181, .360 [a]

Note: [a] Two-tailed correlational analysis.

Exploratory Longitudinal Associations (Inhibitory Control)

Table 25 reports the results of two-tailed Spearman's correlational analyses (H10 – H12). Results are consistent with those reported in Chapter 7.

Table 25. Appendix E. Exploratory Longitudinal 'Hot' and 'Cool' Inhibitory Control Associations.

Type	Tasks	Assessment Points	Statistic
Cool and Hot	ECITT (infancy) and Treasure Delay	10-months and 3½ years	r_s (70) = .196, p = .099, *CI* = -.061, .432
		16-months and 3½ years	r_s (37) = .056, p = .733, *CI* = -.270, .402
Cool and Hot	ECITT (infancy) and Gift Delay	10-months and 3½ years	r_s (78) = -.137, p = .227, *CI* = -.360, .069
		16-months and 3½ years	r_s (43) = .003, p = .982, *CI* = -.271, .295
Cool and Hot	ECITT (infancy) and Dinky Toys	10-months and 3½ years	r_s (67) = -.104, p = .397, *CI* = -.317, .163
		16-months and 3½ years	r_s (39) = -.001, p = .997, *CI* = -.360, .340

Early Inhibitory Control and Pre-Academic Outcomes: Within-Age Associations

Results of within-age Spearman's correlational analyses between inhibitory control measures and performance on tasks of early academic skills (H13 – H14) are reported in **Table 26** below. An additional exploratory correlational analysis was conducted to examine whether performance on the Numbers task and the VCI task was correlated; results suggest

a significant moderate positive association: r_s (87) = .568, p < .001, *CI* = .389, .719. Results are consistent with those reported in Chapter 7.

Table 26. Appendix E. Within-Age Associations: Inhibitory Control and Pre-Academic Outcomes.

Type	Tasks	Pre-Academic Outcome	Statistic
Hot	Treasure Delay	Numbers	r_s (82) = .145, p = .189, *CI* = -.089, .364[a]
		VCI	r_s (79) = .118, p = .293, *CI* = -.099, .347[a]
	Gift Delay	Numbers	r_s (119) = .120, p = .191, *CI* = -.055, .278[a]
		VCI	r_s (87) = .139, p = .194, *CI* = -.072, .337[a]
	Dinky Toys	Numbers	**r_s (94) = .383, p < .001***, *CI* = .177, .549** [a]
		VCI	**r_s (77) = .328, p = .003**, *CI* = .112, .514** [a]
Cool	Go / No Go (Impulse Control)	Numbers	r_s (100) = .097, p = .335, *CI* = -.139, .299 [a]
		VCI	r_s (72) = .186, p = .113, *CI* = -.051, .417 [a]

Note. VCI = Verbal Comprehension Index (from the WPPSI). [a] Two-tailed correlational analysis.

Exploratory Longitudinal Associations: Infant Inhibitory Control and Pre-Academic Outcomes

Results of exploratory longitudinal (H15 – H16) are reported in **Table 27** below. Results are consistent with those reported in Chapter 7.

Table 27. Appendix E. Exploratory Longitudinal Associations: Infant Inhibitory Control and Pre-Academic Outcomes.

Type	Tasks	Assessment Points	Statistic
Cool	ECITT (infancy) and Numbers	10-months and 3½ years	r_s (80) = -.023, p = .835, *CI* = -.230, .190
		16-months and 3½ years	r_s (44) = -.133, p = .379, *CI* = -.436, .188
Cool	ECITT (infancy) and VCI	10-months and 3½ years	r_s (76) = -.069, p = .551, *CI* = -.305, .182
		16-months and 3½ years	r_s (39) = .112, p = .487, *CI* = -.249, .467

Note: VCI = Verbal Comprehension Index (from the WPPSI). All analyses were exploratory (two-tailed).

3. Additional Post-Hoc Exploratory Tests

Section 5.2.5. of the Discussion section of Chapter 7 describes significant associations between performance on the Dinky Toys task ('hot' inhibitory control) and performance on the Numbers and VCI tasks at 3½ years. Post-hoc exploratory analyses were conducted to further investigate potential reasons for this association. The results are described below.

Partial correlational analyses

Post-hoc exploratory analyses revealed that when controlling for performance on the VCI task, the association between performance on the Dinky Toys task and the Numbers task was no longer significant: r (74) = .210, p = .064, *CI* = -.052, .454. Similarly, when controlling for performance on the Numbers task, the association between performance on the Dinky Toys task and the VCI tasks was no longer significant: r (74) = .173, p = .129, *CI* = -.064, .372.

Correlational analyses with the Full Scale IQ variable (WPPSI)

Further post-hoc exploratory analyses revealed that there was a significant, moderate positive association between performance on the Dinky Toys task and FSIQ: r_b (89) = .263, p < .001, *CI* = .114, .406. Similarly, strong significant positive associations were found between FSIQ and performance on the Numbers task: r (101) = .605, p < .001, *CI* = .473, .709, and the VCI task: r (88) = .838, p < .001, *CI* = .783, .882. Results remained significant when controlling the FDR.

Regression analyses with the Full Scale IQ variable (WPPSI)

The overall regression model with FSIQ as a predictor variable and Dinky Toys as the outcome variable was statistically significant, explaining 36.8% of the variance in Dinky Toys performance: adjusted R2 = .126, F (1, 89) = 13.982, p <.001. The analysis showed that FSIQ was a significant predictor of Dinky Toys performance: B = .058, *CI* = .029, .088, t (90) = 3.739, p <.001.

Appendix F

Chapter 8: General Discussion

1. Distraction Strategy Behavioural Coding Scheme

Table 28 and **Table 29** display the behavioural coding schemes used to code children's strategy use at the 3½ year assessment point during the Gift Delay Task and the Treasure Delay Task. These are based on the behavioural coding scheme used in Mulder et al. (2019). Behaviour during the Gift Delay Task was coded across a period of 3 minutes, and behaviour during the Treasure Delay Task was coded for each trial (3 trials maximum; 30-second wait period) where the child chose to wait for the larger amount of treasure. For the Gift Delay task, the total number of strategies used across the 3 minutes was calculated – no information about the number of times a single strategy was used was recorded (i.e., if a child pointed at the gift bag three times, it was only recorded once). However, it would be possible to obtain frequency information from the video of the session. The same applies to the Treasure Delay task, however here the number of strategies used in each trial was recorded as well as the number of strategies used across the whole task.

Table 28. Appendix F. Distraction Strategy Coding Scheme for the Gift Delay Task.

Modality	Type	Behaviour
Visual	Focus	Looks towards object
	Withhold	Eyes are closed
	Distract	Looks at door
		Looks behind (at parent, shelves or dividing wall)
		Looks at his/her own hands
		Looks at a cue in the environment
Verbal	Focus	Talk/ ask questions about the object to someone else
		Talks about what they are doing regarding the object to someone else
		Talks/Asks questions about the object/what they are doing to him/herself
		Talks/asks about the experimenter with someone else
		Talks/asks about the experimenter to self
	Withhold	Repeats the rule regarding the task to someone else
		Repeats the rule regarding the task to themselves
	Distract	Making contact with others (generally)
		Talks about object un-related actions/asks general questions to someone else
		Sings or hums, makes noises (not language), muttering
		Talks in general to him/herself or talks about what they are doing to themselves
		Does not speak
Motor - Hands	Focus	Almost touching the object
		Reaching or pointing toward object
	Relaxed	Hands are (relaxed) above the table
	Withhold	Hands are placed on top of one another
		Holding own hands/arms
		Hands are underneath the table
		Sits on own hands
		Head resting on hands
	Distract	Touches own face or mouth
		Fine motor movements (e.g., fiddles with clothes, fingers)
		Points at/signals to another object in the room
		Hand gestures to parent
		Tapping/rubbing hands on table/legs
	Failure	Low: Child touches, holds or shakes object
		Medium: The child unpacks the object
		High: The child uses the object
Motor - Whole Body	Distract	Child is turned to face parent/wall behind them
		Rocks or dances with body
		Child is away from the table
		Fidgeting with legs/wobbling legs
		Lay down their head on back of chair/table
		Child is under the table
	Failure	Stands up in chair to peek in bag

Table 29. Appendix F. Distraction Strategy Coding Scheme for the Treasure Delay Task.

Type	Behaviour
Passive	Passive Waiting (adult-like waiting - at rest, hands relaxed, watching timer silently
Distract / withhold (away from reward)	Looking around room
	Looking at parent
	Hand gesture to parent
	Looking at E1
	Talking about things (NOT the task)
	Fiddling with hands
	Holding hands / holding hands against table
	Tapping hands on table
	Head in hands (both hands on cheeks - resting head in hands)
	Fidgeting in chair
	Tapping feet on footrest
	Hands in mouth
	Hands on face / head / hair
	Arms / hands crossed
	Sighs
	Leaning on table / head on arms
	Hands underneath the table
	Body across table to look at timer
	Fine motor movements (e.g., fiddling with clothes, other objects)
	Pushes tray of 2 away
Focus (on treat)	Looking at treasure/chest/pirate
	Talking about treasure/chest/pirate (can include pointing)
	Talking about timer (can include pointing)
	Giggling / Excited Big Smile / Grin
Focus (on waiting)	Tongue sticking out
Other	Talking inaudibly
Failure	Takes the treasure (chose tray of 5 but doesn't wait until the end)

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