Five10Twelve Ltd

[redacted]

To: Secretary of State for Transport
% Planning Inspectorate,
National Infrastructure Planning

Date: 19 November 2021
Our Ref: SoS/R/018

Email: manstonairport@planninginspectorate.gov.uk

For the attention of the Manston Airport Case Team

A. This submission is in response to the SoSFT's letter of 21 October 2021 and specifically paragraph 6.

B. We submit our comment to the First Round of Consultation herewith as a formal consultation response to the Second Round of Consultation.

C. Our comment is in response to Kent County Council's submission [TR020002-005741].

D. Kent County Council ("**KCC**") at paragraph 2 of [TR020002-005741] states that: "*The County Council has previously provided full comments in response to the deadlines associated with the Development Consent Order (DCO) formal consultation process and would refer to these submissions, which remain relevant to the consideration of this DCO*[1]".

E. Kent County Council at its last paragraph of [TR020002-005741] states: "*The County Council requests that the Examining Authority has due consideration of KCC's submissions throughout this Examination process when assessing the proposal*[2]".

F. We respectfully remind the Secretary of State that on 17 January 2020 KCC

[1] Page 1, para 2 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-005741-Kent%20County%20Council.pdf (accessed on 19 November 2021)

[2] Page 2, last paragraph https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-005741-Kent%20County%20Council.pdf (accessed on 19 November 2021)

submitted a very detailed response of significant concerns *inter alia* in relation to insufficient provision to mitigate and minimise the noise of effects at schools[3].

G. As you will be aware, KCC stated at paragraph 3 of the said submission that:

"*KCC does not know how the education contributions were calculated or how the schools listed were identified. In response to the ExA's Second Written Questions, the County Council provided an estimate in respect of the potential costs associated with insulating and ventilating a primary school in Kent as £300,000. The exact amount will depend on the matters listed in KCC's response and KCC is not aware that the methodology has been set out in any of the applicant's documents submitted and in particular the revised Noise Mitigation Plan*[4]" (underline added for emphasis).

H. The number of schools identified by the Applicant to receive noise mitigation measures totalled 7[5].

I. Information submitted by KCC during the examination identified 45 schools within 5 miles from the Proposed Development; Manston Airport[6].

J. Information submitted by us during the examination identified 17 schools and nurseries that would fall under the proposed flight path in Ramsgate alone[7].

K. We respectfully refer the Secretary of State to our response labelled

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[3] Page 1 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-005259-Kent%20County%20Council%20response%20to%20request%20for%20further%20information.pdf (accessed 17 November 2020)

[4] Page 1, paragraph 3 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-005259-Kent%20County%20Council%20response%20to%20request%20for%20further%20information.pdf (accessed 17 November 2020)

[5] Applicant's Unilateral Undertaking page 17 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-005299-Unilateral%20undertaking%20to%20Kent%20County%20Council%20(tracked).pdf (accessed 19 November 2021)

[6] Kent County Council Copy of Appendix 1 and 2 Available online at: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-004611-KCC%20Copy%20of%20Appendix%201%20and%202%20-%20Schedule%20of%20schools%20within%20radius%20of%20Manston%20Airport.pdf (accessed 19 November 2021)

[7] [REP9-063] Page 3 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR020002/TR020002-004464-Five10Twelve%20Ltd%20-%20Comment%20on%20REP8-004%20Number%20of%20Schools%20and%20Nurseries%20that%20Fall%20within%20Each%20of%20the%20Noise%20Contours_.pdf (accessed 19 November 2021)

SoS/R/012 submitted on 18 November 2021 specifically at Page 32, Para BB and for ease of reference submitted below with further information.

L. **New evidence** reported in CAP 2257 by the Civil Aviation Authority in September 2021[8] states at para 3.30:

"Children's Learning

3.30 Clark et al published a meta-analysis of the association between aircraft noise at school on children's reading comprehension and psychological health. The data from three studies carried out in 106 schools near London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports (the Schools Environment and Health Study, the West London Schools Study, and the RANCH study), using the Strengths and Difficulties Questionnaire, were analysed. The authors reported that ***a 1 dB increase in aircraft noise exposure at school was associated with a –0.007 (95%CI –0.012 to –0.001) decrease in reading score and a 4% increase in odds of scoring well below or below average on the reading test "*** (bold added for emphasis).

M. There has been **no aircraft noise exposure** in the community and at schools or child care facilities in and around Ramsgate for **over 7 years.**

N. The Applicant's noise mitigation measures are clearly insufficient in scope and amount.

O. **New information**

We attach the full report referred to by the CAA in CAP 2257[9] herewith labelled: A Meta-Analysis of the Association of Aircraft Noise at School on Children's Reading Comprehension and Psychological Health for Use in Health Impact Assessment.

P. It is specific to noise effects on children's cognition and their application in

[8] Para 3.30 Aircraft Noise and Health Effects – a six monthly update Environmental Research Consultancy Department CAP 2257 Available online at: [redacted] (accessed 19 November 2021)

[9] *Ibid*

Health Impact Assessment and methodologies to monetise the effects of noise on health.

Q. It concludes at Page 11, para 5[10] that:

"*Reading comprehension should be taken into account in* *__Health Impact Assessment and monetisation methodologies__*".

R. It concludes at Page 11, para 5[11] that:

"*The analyses confirm existing evidence for effects of aircraft noise exposure on children's reading comprehension, and* *__provide additional estimates for scoring 'well below or below average' on the reading test__*". (underlined for emphasis)

S. Table of Showing the Relationship between reading age, education and life outcomes[12]:

The effect of reading ability continues throughout life. Compared to their counterparts with 'functional literacy' levels (a reading age of 11 or above), individuals with low reading ability are:	
Less likely to gain employment, particularly skilled roles	More likely to exhibit behavioural problems and delinquency
Less like to earn an above average salary	More likely to offend, be incarcerated and develop a habit of lifelong offending
Less likely to achieve qualifications or receive work based training or promotion	More likely to have low levels of psychological wellbeing and life satisfaction
Less likely to use preventative health services, remain healthy or manage treatment and medications well	

[10] Attached herewith: A Meta-Analysis of the Association of Aircraft Noise at School on Children's Reading Comprehension and Psychological Health for Use in Health Impact Assessment, Charlotte Clark, Jenny Head, Mary Haines, Irene van Kamp, ELise van Kempen, Stephen A. Stansfield

[11] Attached herewith: A Meta-Analysis of the Association of Aircraft Noise at School on Children's Reading Comprehension and Psychological Health for Use in Health Impact Assessment, Charlotte Clark, Jenny Head, Mary Haines, Irene van Kamp, ELise van Kempen, Stephen A. Stansfield

[12] he relationship Between Reading Age, Education and Life Outcomes, Ellie Mulcahy, Eleanor Bernardes and Dr Sam Baars Available online at: [redacted]. (accessed on 19 November 2021)

T. Reading ability has a considerable impact on both educational attainment and wider life outcomes. As poor reading ability is associated with such profound negative life outcomes, it can have huge cost to an individual and also to the economy[13].

U. The Proposed Development will harm Ramsgate and the wider Thanet; its residents and its economy.

13 [redacted] (accessed 19 November 2021)

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A meta-analysis of the association of aircraft noise at school on children's reading comprehension and psychological health for use in health impact assessment

Charlotte Clark [a,*], Jenny Head [b], Mary Haines [c], Irene van Kamp [d], Elise van Kempen [d], Stephen A. Stansfeld [e]

[a] Population Health Research Institute, St George's, University of London, Cranmer Terrace, Tooting, London, SW17 0RE, UK
[b] Department of Epidemiology and Public Health, University College London, 1-19 Torrington Place, London, WC1E 7HB, UK
[c] Menzies Centre for Health Policy, School of Public Health, The University of Sydney NSW, 2006, Australia
[d] National Institute for Public Health and the Environment, 3721, MA Bilthoven, the Netherlands
[e] Centre for Psychiatry, Barts & the London School of Medicine, Queen Mary University of London, EC1M 6BQ, UK

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ABSTRACT

Whilst the effects of aircraft noise on children's cognition are well-accepted, their application in Health Impact Assessment (HIA) and methodologies to monetise the effects of noise on health have been limited. This paper presents the first meta-analysis of the effect of aircraft noise at school on children's reading comprehension and psychological health assessed with the Strengths and Difficulties Questionnaire. Data from three methodologically similar studies carried out in 106 schools near London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports (the Schools Environment and Health Study, the West London Schools Study, and the RANCH study) were analysed finding that a 1 dB increase in aircraft noise exposure at school was associated with a −0.007 (95%CI −0.012 to −0.001) decrease in reading score and a 4% increase in odds of scoring well below or below average on the reading test. The analyses also found that a 1 dB increase in aircraft noise exposure at school was associated with a 0.017 (95%CI 0.007–0.028) increase in hyperactivity score. No effects were observed for emotional symptoms, conduct problems or Total Difficulties Score. Meta-analyses confirm existing evidence for effects of aircraft noise exposure on children's reading comprehension, providing a pooled estimate and exposure-effect relationship, as well as additional estimates and relationships for effects on scoring 'well below or below average' on the reading test offering flexibility for taking reading comprehension into account in HIA and monetisation methodologies in a wide-range of contexts.

1. Introduction

1.1. Environmental noise effects on children's cognition and health

1.1.1. Environmental noise effects on reading comprehension

For nearly fifty years, researchers have attempted to quantify the effect of environmental noise exposure on children's learning and cognitive skills (Bronzaft, 1981; Clark et al., 2006; Cohen, Glass, & Singer, 1973; Cohen, Krantz, Evans, Stokols, & Kelly, 1981; Haines, Stansfeld, Brentnall, et al., 2001; Haines, Stansfeld, Head, & Job, 2002; Haines, Stansfeld, Job, Berglund, & Head, 2001; Hygge, Evans, & Bullinger, 2002; Klatte, Spilski, Mayerl, & Bergström, 2016; Stansfeld et al., 2005). Over-time there has been increasing diversification and standardisation of the types of cognitive skills examined covering memory, reading skills, attention, executive function as well as standardised academic test scores, and better characterisation of noise exposure in school and home environments (Clark & Paunović, 2018a).

In the UK, one of the first studies of aircraft noise on children's cognition was the **Schools Environment and Health Study (SEHS)** which compared the reading comprehension of children aged 9–10 years, attending four schools near London Heathrow airport exposed to high levels of aircraft noise (>66 dB $L_{Aeq,16hr}$) with children attending four matched control schools exposed to lower levels of aircraft noise (<57 dB $L_{Aeq,16hr}$) (Haines, Stansfeld, Job, et al., 2001). Environmental

* Corresponding author.
E-mail address: chclark@sgul.ac.uk (C. Clark).

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noise exposure is typically assessed in decibels (dB) using an average metric covering the day-time period (7am-11pm), referred to as $L_{Aeq,16h}$. The SEHS found that chronic exposure to aircraft noise was associated with impaired reading comprehension after adjustment for socioeconomic confounders. This study was followed by a larger study employing a similar methodology (**The West London Schools Study: WLSS**) which compared the reading comprehension of children from ten high-noise schools near London Heathrow airport with that of children from ten matched control schools (Haines, Stansfeld, Brentnall, et al., 2001). The results indicated that children in the noise exposed schools had poorer reading performance but only on the most difficult items of the reading test.

The SEHS and the WLSS informed the European Union funded **RANCH study** in the early 2000s (Road Traffic and Aircraft Noise and children's Cognition and Health), which remains the largest study of the effects of aircraft noise on children's learning and health to date (Clark et al., 2006; Stansfeld et al., 2005; Stansfeld et al., 2009). The RANCH study was a cross-national cross-sectional study of 2844 children aged 9–10 years attending 89 schools near London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports in 2002–2003. Cognitive and health outcomes were measured using the same standardised measures across countries and parents completed questionnaires about socio-demographic factors.

The RANCH study found a linear exposure-effect relationship between chronic aircraft noise exposure and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account including mother's education, long-standing illness, the extent of classroom insulation against noise, and acute noise during testing (Stansfeld et al., 2005). A 5 dB $L_{Aeq,16h}$ increase in aircraft noise exposure was associated with a two month delay in reading age in the United Kingdom (UK) and a one month delay in the Netherlands (Clark et al., 2006). No associations were observed between chronic road traffic noise exposure and cognition, with the exception of conceptual recall and information recall, which surprisingly showed better performance in high road traffic noise areas. Neither aircraft noise nor road traffic noise affected attention or working memory. In the UK, the RANCH participants were followed up six years later in secondary school, finding a trend for reading comprehension to be poorer at 15–16 years of age for children who attended noise exposed secondary schools (Clark, Head, & Stansfeld, 2013).

1.1.2. Environmental noise effects on children's psychological health

Whilst the initial focus was on the effects of environmental noise on children's learning outcomes, over the past two decades concerns about effects of noise on children's psychological health have increased (Clark, Crumpler, & Notley, 2020; Clark & Paunović, 2018b; Evans, Bullinger, & Hygge, 1998; Schubert et al., 2019; Stansfeld et al., 2009; Tiesler et al., 2013). Both the RANCH study and the WLSS found a significant effect of aircraft noise on hyperactivity but the SEHS did not find an effect. A recent meta-analysis, which statistically combines the results of multiple studies, estimated that a 10 dB increase in road traffic noise was associated with a 11% increase in odds for hyperactivity and a 9% increase in odds for Total Difficulties Score (TDS) based on estimates from three studies from Germany, Denmark and Korea (Schubert et al., 2019). No meta-analysis for aircraft noise was presented and generally methodological differences and characterisation of noise between studies have limited meta-analyses in this field (Clark & Paunović, 2018b). Conclusions regarding the effects of noise on emotional symptoms, conduct disorders and general psychological distress is equivocal across studies. Further pooling of estimates via meta-analysis focusing on aircraft noise exposure would be beneficial for this field.

1.2. Health impact assessment

One major contribution of the RANCH study was that the exposure-effect relationship identified between aircraft noise and reading comprehension made it possible to start to quantify the magnitudes of aircraft noise induced impairments on children's cognition for use in Environmental Impact Assessment and Health Impact Assessment (European Environment Agency, 2020; National Institute for Public Health and the Environment (RIVM), 2018; "The Town and Country Planning (Environmental Impact Assessment) Regulations 2017 "; WHO, 2011). The exposure-effect relationship between aircraft noise exposure and reading comprehension (Clark et al., 2006), has been used to guide decision making by stakeholders and policy makers, as well as to estimate the benefits of noise reduction and mitigation for large infrastructure projects (High Speed two Limited, 2017). The relationship indicates that reading falls below average (a Z-score of 0) at exposures greater than 55dBA $L_{Aeq,16h}$: however, as the relationship between aircraft noise and reading comprehension is linear, reducing exposure at any level should lead to improvements in reading comprehension. A similar linear relationship has subsequently been identified in the German NORAH study (Noise-Related Annoyance, Cognition, and Health) (Klatte et al., 2016).

Health Impact Assessment relies upon the availability of epidemiological evidence for the effect of an exposure such as noise on the outcome. Over-time evidence can build or change and it is methodologically robust to use estimates of noise effects from more than one study as provided by meta-analysis, if available, rather than evidence from only one study. To date, undertaking meta-analysis of the effects of aircraft noise at school has proved extremely challenging due to the differing range of cognitive tests employed across studies and countries, the confounders taken into account, as well as variation in studies comparing high versus low exposure groups versus continuous assessment of noise exposure (Clark et al., 2020; Clark & Paunović, 2018a). The three studies of primary school children carried out around London Heathrow, Amsterdam Schiphol and Madrid Barajas airports described earlier (SEHS, WLSS, RANCH), share a methodology that would lend itself to meta-analysis, with some additional post-hoc analysis.

In the UK, the current guidance for economically valuing the health impacts associated with environmental noise is published by Defra (the Department for the Environment, Food, and Rural Affairs) on behalf of the Interdepartmental Group on Costs and Benefits (Noise Subject Group) (IGCB(N)), with the current guidance relying on evidence for noise and health effects published up to 2014 (Defra, 2014; Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)), 2010). This guidance informs the government's Transport Appraisal Guidance for noise (Department for Transport, 2015), and Her Majesty's Treasury Green Book on appraisal and evaluation in central government (HM Treasury, 2018), both of which monetise the effects of noise on health. The existing guidance covers the effects of aircraft noise, road traffic noise, or railway noise on acute myocardial infarction, annoyance, stroke, vascular dementia, and sleep disturbance. Children's cognition has not been included to date, as the methodology to monetise noise effects on health requires evidence for a dichotomous not a continuous outcome (Clark et al., 2020). The RANCH study analysed a continuous reading Z-score. This means that the effects of environmental noise on children's learning is not currently monetised in environmental impact appraisal for projects and schemes, such as the expansion of aviation or airspace change (Civil Aviation Authority, 2018) or new infrastructure (High Speed 2 Limited, 2017). Yet effects on children's learning remain a key concern of impacted communities. Increasing evidence for effects of environmental noise on children's psychological health could also be incorporated into these planning tools.

The aim of this paper was to reanalyse the SEHS, the WLSS, and the RANCH study to enable meta-analyses for the effects of aircraft noise at school on children's reading comprehension and psychological health to be carried out, to provide a pooled estimate for the effects for use in HIA. The aim of the meta-analyses was to quantify effects for a 1 dB increase in aircraft noise exposure for both continuous and categorical assessments of reading comprehension and psychological health, to allow flexibility for use in HIA and monetisation tools. The focus on these three studies which use a similar methodology overcomes the issues encountered to date of combining estimates across studies which use different methods (Clark et al., 2020; Clark & Paunović, 2018a) to start to build information about pooled effects for HIA and monetisation tools both within the UK and beyond.

2. Methods

2.1. Sampling and design

In the SEHS, the WLSS, and the UK sample of the RANCH study (hereafter, referred to as the RANCH-UK study), children were selected based on annual average ($L_{Aeq,16h}$) aircraft noise exposure in their school from contours published by the Civil Aviation Authority. L_{Aeq} is the equivalent average sound level measured in decibels (dB) using the A-weighting most sensitive to speech intelligibility frequencies of the human ear. Contours for the year 1996 were used for the SEHS; for the year 1999 for the WLSS; and for the year 2000 for the RANCH-UK study. These noise contours estimate noise for the school postcode for the three-month summer period (July to September) between 7am and 11pm. In the Dutch sample of the RANCH study (RANCH-NL study), aircraft noise was based on modelled data linked to school locations with geographical information systems. In the Spanish sample of the RANCH study (RANCH-Spain) aircraft noise was based on predicted noise contours. Within each study, schools were matched according to socioeconomic status on the percentage of children receiving free school meals and speaking the main language at home. Mixed ability classes of 9–10 year old children from the selected schools were selected to participate. No children were excluded from the selected classes.

The full-methodologies for the studies are described in full detail elsewhere (Clark et al., 2013; Clark et al., 2006; Haines, Stansfeld, Brentnall, et al., 2001; Haines, Stansfeld, Job, et al., 2001; Stansfeld et al., 2005). The re-analysis of the SEHS was undertaken on data from seven schools rather than eight school, due to a procedural error as reported in the original paper (Haines, Stansfeld, Job, et al., 2001).

2.2. Measures

2.2.1. Noise exposure assessment

As previously described, for all three studies aircraft noise estimates were based on 16-h outdoor L_{Aeq}. The aircraft noise contour data were available nationally in the UK and Spain and were not derived specifically for the studies. In the analyses, aircraft noise exposure was entered as a continuous variable in dB(A).

The SEHS and WLSS studies previously reported the effect of aircraft noise on reading comprehension and the Strengths and Difficulties Questionnaire (SDQ) by grouping the schools into <57 dB $L_{Aeq,16h}$ or above 63 dB $L_{Aeq,16h}$. For this reanalysis, the mid-point of the contour band was assigned for the analysis e.g. <57 dB = entered as mid-point (55.5 dB) between 54 and 57 dB contour; 63–66 dB entered as 64.5 dB; and 66–69 dB entered as 67.5 dB. Sensitivity analyses using the top-data point and low-data point for each category produced comparable estimated to those reported.

2.2.2. Reading comprehension

All studies used nationally standardised tests of reading comprehension. The three UK studies (SEHS, WLSS, RANCH-UK) measured reading comprehension using the nationally standardised 86 item Suffolk Reading Scale (Hagley, 2002). The studies used the level 2 scale which is suitable for children aged 8 years–11 years of age. The standardised scores on the Suffolk Reading Scale were Z-scored for analysis (mean = 0, SD = 1).

The raw scores on the Suffolk Reading Scale can also be categorised into the following categories: <70 well below average; 70–84 below average; 85–94 low average; 95–104 average; 105–114 high average; 115–129 above average; above 129 well above average. To create a dichotomous categorical reading impairment variable for reanalysis, the lowest two categories (well below average and below average) were combined and compared with low average to well above average scores. These categorical data have not previously been reported for these studies, and are considered a post-hoc analysis.

The RANCH-NL study measured reading comprehension using the CITO (Centraal Instituut Toets Ontwikkeling) readability index for elementary and special education (Staphorsius, 1994). The RANCH-Spanish study measured reading comprehension using the ECL-2 (Evaluación de la Compresión lectora, nivel 2) (De La Cruz, 1999). Scores on these measures were also Z-scored for analysis.

2.2.3. Psychological health

The SEHS, WLSS, and RANCH study all assessed psychological health using the psychometrically robust SDQ (Goodman, 1997; Goodman & Goodman, 2009). The SDQ is a standardised 25 item screening questionnaire that covers five domains: emotional symptoms; conduct problems; hyperactivity; pro-social behaviour; and peer-relationship problems. In all studies, the child's parent completed the SDQ. A TDS ranging from 0 to 40, is calculated by adding the scores for hyperactivity, emotional symptoms, conduct problems and peer problems. The SDQ provides cut-off scores for each scale and the TDS to indicate whether the score is 'normal', 'borderline' or 'abnormal'. In this analysis, categorical SDQ caseness was defined as 'normal' versus 'borderline or abnormal'. The TDS, emotional symptoms, conduct problems and hyperactivity scores (continuous and categorical) were analysed.

2.2.4. Confounding factors

Analyses took into account socioeconomic factors that were likely to influence exposure to noise at school, reading comprehension, and/or psychological health. In all studies, comparable measures of socio-demographic factors were available from questionnaires completed by the child and parent. The RANCH study retained potential confounding variables in the analyses if analysis of covariance showed a significant relation between the confounder and aircraft noise exposure ($p < 0.05$), retaining age; parent employment status; whether the parent worked full or part-time; crowding in the home; home ownership; child's long-standing illness; main language spoken in the home; classroom glazing of the windows in the child's classroom; mother's educational attainment; and parental support for schoolwork. These confounders were used in additional analyses of the RANCH-UK study undertaken for this paper.

Most of the same confounding variables were also available in the earlier SEHS and WLSS with the exception of parental support for schoolwork, classroom glazing, and long-standing illness. The SEHS and WLSS re-analyses therefore adjust for a slightly reduced number of confounders. Sensitivity analyses undertaken on the RANCH study data reanalysing the estimates with the reduced set of confounders excluding parental support, classroom glazing and long-standing illness made little difference to the estimates suggesting comparative homogeneity between the effect the slightly different sets of confounders have within each study.

2.3. Procedure

The reading comprehension data for all studies was from group testing carried out in the classroom and the reading tests were administered as part of a testing session conducted in the morning of a normal school day. Written consent was obtained from both parents and children for all studies, and ethical approval was obtained for each study (see Appendix). Parents completed questionnaires on sociodemographic factors and psychological health.

Table 1
Summary of the school and pupil level characteristics of the SEHS, WLSS, RANCH study and RANCH-UK study.

Characteristic	SEHS	WLSS	RANCH study - pooled UK, Netherlands and Spanish samples[a]	RANCH study -UK sub-sample
Year of Study	2001	2001	2005	2005
School level data	n = 7	n = 10	N = 89	n = 29
Number of pupils participating	340	451	3207	1174
Aircraft noise exposure at school dB $L_{Aeq,16h}$				
Mean (SD)	61.2 (5.22)	60.3 (6.22)	52 (9.7)	52 (9.4)
Range	55–66	54–69	30–77	34–68
Road traffic noise exposure at school dB $L_{Aeq,16h}$				
Mean (SD)	n.a.	n.a.	51 (7.57)	48 (7.25)
Range			32–71	37–67
Classroom glazing (%)				
Single glazing	n.a.	n.a.	56.2	58.6
Double glazing			39.3	41.4
Triple glazing			4.5	0.0
Pupil level data				
Response rate (%)				
Child	77	82	89	87
Parent	84	80	90	82
Reading comprehension Z-score (continuous)				
Mean (SD)	0.00 (1.00)	0.00 (1.00)	0.00(1.00)	0.00 (1.00)
Range	−1.42-1.44	−2.31-2.84	−2.36-3.07	−2.09-2.55
Reading comprehension (categorical) (%)				
Scoring well below or below average	13.5	14.6	n.a.	18.4
SDQ (mean/SD) (continuous score range)				
Total Difficulties Score (TDS) (0-40)	8.4 (5.79)	11.0 (5.46)	9.73 (5.73)	9.96 (5.96)
Hyperactivity (0-10)	3.3 (2.51)	4.48 (1.91)	3.83 (2.55)	3.82 (2.48)
Conduct disorder (0-10)	1.4 (1.68)	1.9 (1.74)	1.82 (1.65)	1.81 (1.80)
Emotional problems (0-10)	2.0 (2.01)	2.6 (2.14)	2.41 (2.13)	2.47 (2.23)
SDQ borderline or a case (%) (categorical)				
Total Difficulties Score (TDS)	16.9	31.5	10.7	12.1
Hyperactivity	17.3	29.3	16.6	15.8
Conduct disorder	19.0	31.8	15.1	15.3
Emotional problems	20.3	28.4	16.0	17.6
Age				
Mean	9y-, 8m-	8y-, 8m-	10y-, 6m-	10y-, 3m-
Range	8y7m – 10y,10m	8y1m – 9y8m	8y10m –12y10m	8y10m –11y11m
Sex (%)				
Female	51.3	49.8	52.9	54.9
Employment status (%)				
Not employed	16.9	22.3	14.9	22.7
Crowding (%)				
Crowded	8.2	19.2	21.4	22.7
Home ownership (%)				
Not owned	79.5	37.9	27.7	42.1
Long standing illness (%)				
LSI	n.a.	n.a.	24.1	26.4
Main language spoken at home (%)				
Other language	20.6	36.2	11.9	22.0
Mother's education				
Mean (SD) (continuous)	n.a.	n.a.	.50 (.28)	.50 (.28)
No further education (categorical)	51.1	73.5	n.a.	n.a.
Parental support scale				
Mean (SD)	n.a.	n.a.	10.1 (2.0)	10.1 (1.9)
Cronbach's α			.650	.591

n.a. The measure was not available in the study.
[a] The school and pupil characteristics are provided here for the pooled RANCH sample (combined UK, Dutch, Spanish samples) and the RANCH-UK sample as these are the data analysed for the meta-analyses. Further details about the school and pupil characteristics for the individual RANCH-Dutch and RANCH-Spanish samples are provided in (Stansfeld et al., 2005).

2.4. Analysis

2.4.1. Overview

A meta-analysis takes an estimate for an effect from each individual study, e.g. the association of aircraft noise on reading comprehension, and combines them to provide a pooled estimate of the effect across all the studies. For this paper, some of the estimates needed for the meta-analyses were already published in earlier papers (Clark et al., 2006; Stansfeld et al., 2009) and could be directly entered in the meta-analysis. Some estimates had to be derived for the meta-analysis using additional regression analyses. All analyses were carried out in Stata version 14 (StataCorp, 2015).

2.4.2. Individual study analysis – deriving additional estimates

Data from the SEHS and the WLSS were analysed using multilevel linear regression analysis to estimate the association per 1 dB increase in aircraft noise exposure with the continuous reading comprehension Z-score, as well as the continuous SDQ scores (TDS, emotional symptoms, hyperactivity, conduct problems). Data from the SEHS, the WLSS, and the RANCH study were analysed using multilevel logistic regression analysis to estimate the effect of a 1 dB increase in aircraft noise at school on the categorical reading impairment outcome (well-below or below average) and on the categorical SDQ outcomes (a borderline or abnormal score on the TDS, emotional symptoms, hyperactivity, conduct problems scale). Categorical reading impairment was not examined using the pooled RANCH study dataset which includes the UK, Dutch and Spanish data, as scoring 'well below or below average' was specific to the UK reading test. For all the regressions, two models were run. Model 1 adjusted only for aircraft noise exposure and Model 2 further adjusted for age, gender, mother's educational attainment, parental employment status, crowding in the home, parental home ownership, and main language spoken at home. In these multilevel models, pupil factors were entered as level 1 and school factors as level 2.

2.4.3. Meta-analysis - deriving pooled estimates

Random effects (restricted maximum likelihood) meta-analysis was then conducted for each outcome to obtained pooled estimates. For the continuous outcomes the study's effect size, standard error and 95%

Table 2
Summary of the pooled estimates from the meta-analyses for the continuous and categorical reading comprehension and psychological health outcomes in the UK studies (SEHS, WLSS, RANCH).

Outcome	No effect	Aircraft noise risk effect on the outcome
Continuous reading comprehension		Yes
Categorical reading comprehension		Yes
Continuous TDS	Yes	
Categorical TDS	Yes	
Continuous Emotional Symptoms	Yes	
Categorical Emotional Symptoms	Yes	
Continuous Conduct Problems	Yes	
Categorical Conduct Problems	Yes	
Continuous Hyperactivity		Yes
Categorical Hyperactivity	Yes	

confidence intervals (CI) for a 1 dB increase in aircraft noise on reading comprehension Z-score or continuous SDQ score were analysed. For the categorical outcomes, the study's odds ratio, standard error and 95%CI for a 1 dB increase in aircraft noise on categorical reading impairment or categorical SDQ score were analysed. Heterogeneity– an assessment of the percentage of variation in effect sizes across studies that is not due to chance, are reported using the I^2 statistic.

An effect estimate for a 1 dB unit increase in noise was chosen for all the analyses as it offers precision and flexibility. Future meta-analyses wishing to use the estimates from the three studies can easily use the 1 dB estimate or if they so wish multiply it to get an estimate for a 5 dB or 10 dB increase in noise, where the relationships are linear. The 1 dB estimate allows for ease and precision when plotting exposure-effect relationships and can be applied in environmental and health impact assessment. The 1 dB estimate avoids the limitations of previous studies that have reported exposure for ranges of exposure (e.g. 50–55 dB) which can be difficult to interpret and apply in assessment, policy, and practice.

2.4.4. Deriving exposure-effect relationships

Post-hoc analyses were undertaken to derive an exposure-effect relationship between aircraft noise exposure at school and an outcome, where the meta-analysis showed a statistically significant association in the pooled analysis. To derive the relationship, linear or logistic adjusted multi-level regression models were estimated for the pooled datasets (RANCH, SEH, WLSS) with the predicted scores or probabilities plotted against noise exposure.

3. Results

3.1. Overview

Table 1 summarises the key school and pupil level characteristics of the SEHS, the WLSS and the RANCH study. All of the studies had high response rates. Mean aircraft noise exposure at school was higher for the SEHS and the WLSS studies compared with the RANCH study, but the former studies selected schools with exposures <57 dB or >63 dB $L_{Aeq,16h}$, whereas RANCH examined a wide range of exposures to establish an exposure-effect relationship. There were some differences between the studies. There were higher rates of parental unemployment in the WLSS and the RANCH-UK samples. Levels of homeownership increased markedly across time for the UK samples, as did levels of crowding. Scores on the SDQ were higher in the WLSS sample compared with the SEHS and the RANCH study.

Table 2 provides a summary of the findings of the meta-analyses for each outcome, which are discussed in more detail in the following sections. The Forest plots presented in Figs. 1–4 present the estimate/odds ratio and 95% confidence intervals for the effect of noise on the outcome for each study individually, with the square depicting the weight given to that study in the pooled analyses: the larger the square the larger the weight for that study. The last row in the Forest Plot presents the estimate for the pooled effect estimate across the studies. The dashed line shows the pooled estimate and the diamond depicts the confidence intervals for the pooled estimate, i.e. the lowest and highest values within which the true estimate lies. The solid black vertical line on the Forest Plots depicts 'no effect': if the confidence intervals for any estimate, either from the individual studies or pooled estimate, cross the solid black vertical line there is no statistically significant effect.

3.2. Meta-analysis continuous standardised reading score

Fig. 1 shows the estimates from the re-analyses of the SEHS and the WLSS studies, alongside the original estimate from the RANCH study, estimating the effect of a 1 dB increase in aircraft noise at school on standardised continuous reading scores. For the individual studies, only the RANCH study found a statistically significant decrease in continuous standardised reading scores, with a 1 dB increase in aircraft noise being associated with a −0.008 (95%CI -0.014 to −0.002) decrease in reading Z-score. The results of the meta-analysis of the estimates from the three studies also shows a statistically significant decrease in continuous standardised reading scores, with a 1 dB increase in aircraft noise being associated with a −0.007 (95%CI -0.012 to −0.001) decrease in reading Z-score (Fig. 1). The I^2 indicates low heterogeneity between the studies showing that the study findings are broadly consistent.

3.3. Meta-analysis categorical standardised reading score

Fig. 2 shows the estimates from the re-analyses of the RANCH-UK, the SEHS and the WLSS studies, estimating the effect of a 1 dB increase in aircraft noise at school on the odds of scoring well below or below average on the reading test. For the individual studies, only the RANCH-UK study found a statistically significantly increase in odds of scoring well below or below average on the reading test, with a 1 dB increase in aircraft noise at school being associated with a 4% (95%CI 1%–6%) increase in odds. The SEH showed a borderline significant effect and the WLSS showed no significant effect. The meta-analysis of these estimates found a statistically significantly increase in odds of scoring well below or below average on the reading test, with a 1 dB increase in aircraft noise at school being associated with a 4% (95%CI 2%–6%) increase in odds. The I^2 indicates very low heterogeneity between the studies showing that the findings are consistent across the studies.

3.4. Meta-analysis continuous psychological health outcomes

Fig. 3 shows the estimates from the re-analyses of the WLSS and the

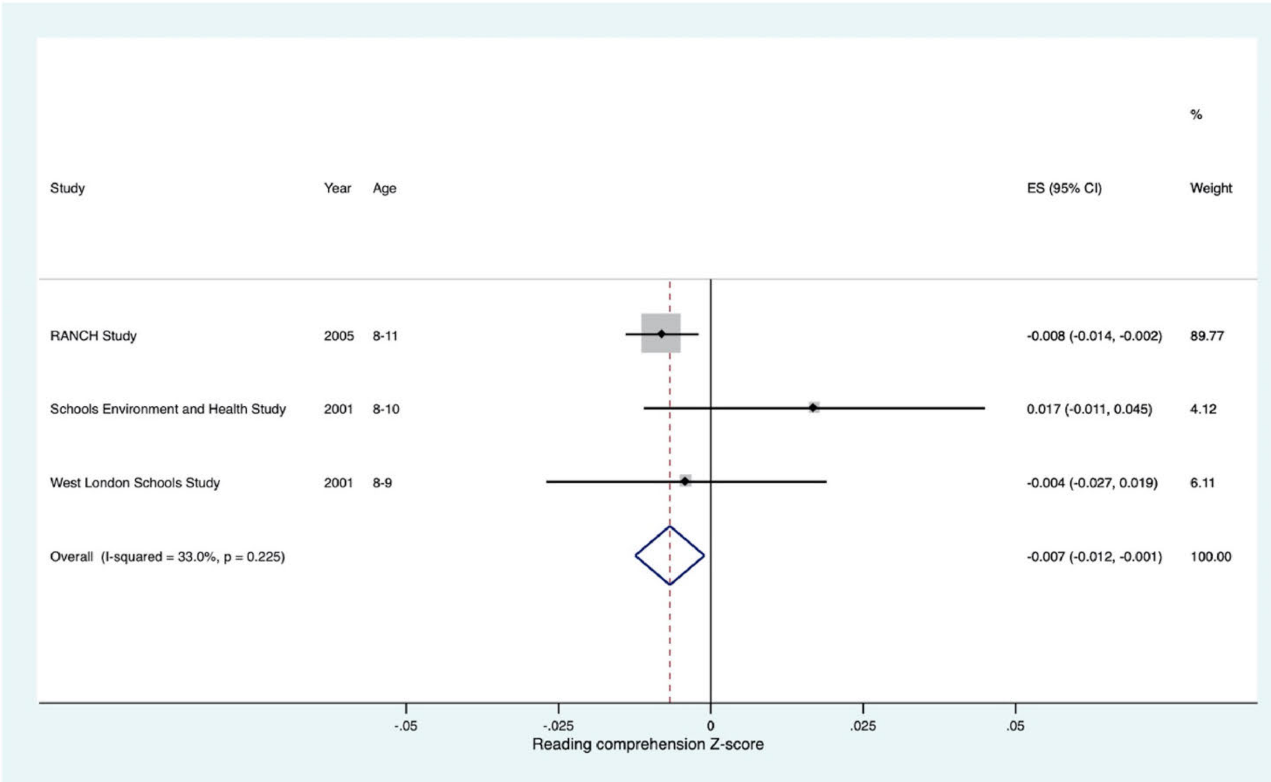

Fig. 1. Forest plot showing the association of a 1 dB increase in noise exposure at school ($L_{Aeq,16h}$) on continuous standardised reading scores for the RANCH study, the SEHS, and the WLSS.

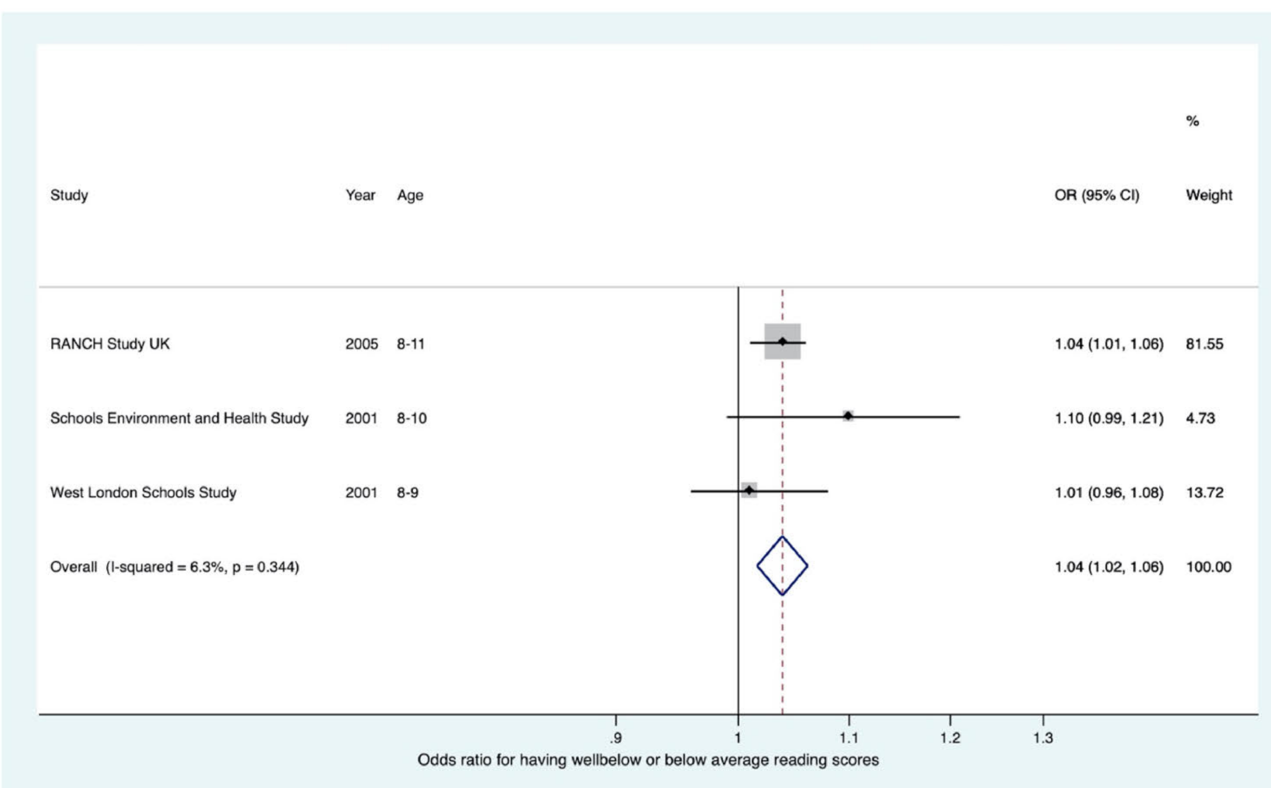

Fig. 2. Forest plot showing the association of a 1 dB increase in noise exposure at school ($L_{Aeq,16h}$) on odds of having well below or below average standardised reading scores in the RANCH-UK, the SEHS, and the WLSS.

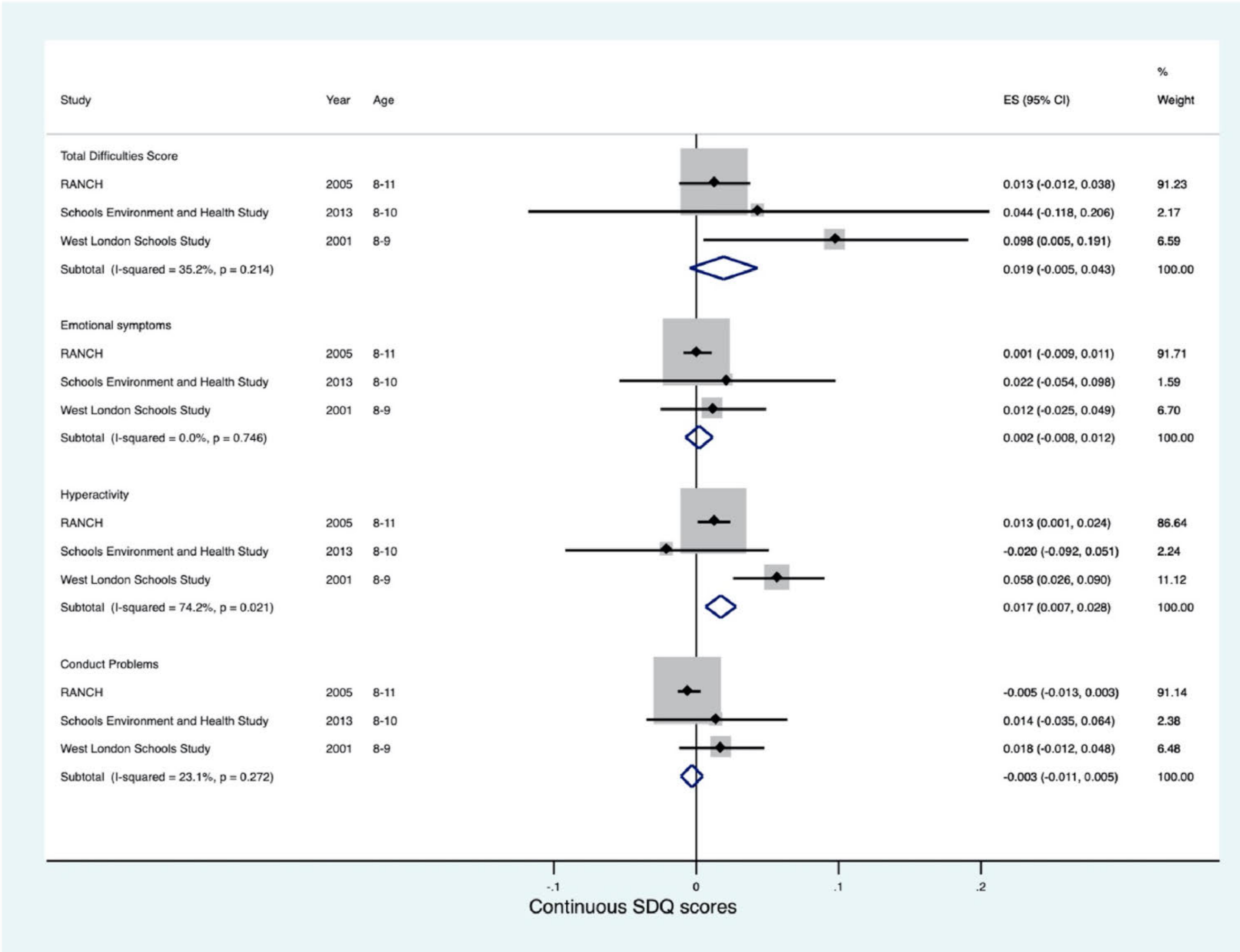

Fig. 3. Forest plot showing the association of a 1 dB increase in noise exposure at school ($L_{Aeq,16h}$) on continuous total difficulties score, emotional symptoms score, hyperactivity score and conduct problems score from the SDQ for the RANCH study, the SEHS, and the WLSS.

SEHS, alongside the original estimates from the RANCH study and the meta-analyses estimating the effect of a 1 dB increase in aircraft noise at school on the continuous TDS, emotional symptoms, hyperactivity and the conduct problems scales, respectively.

The pooled estimates showed no significant association of aircraft noise at school on the TDS, the emotional symptom scale or conduct problem scale scores. The pooled estimates showed a statistically significant increase in hyperactivity for a 1 dB increase in aircraft noise at school ($\beta = 0.017$ 95%CI 0.007 to 0.028), with substantial heterogeneity between the studies. Study findings vary considerably across the studies.

3.5. Meta-analysis categorical psychological health outcomes

Fig. 4 shows the estimates from the re-analyses of the RANCH study, the SEHS and the WLSS and the subsequent meta-analyses, which showed no significant associations between aircraft noise and the odds of being borderline or a case on the TDS, the emotional symptoms scale, the conduct problems scale or the hyperactivity scale. The I^2 indicated low heterogeneity between the studies for the TDS, emotional symptoms and conduct problems but moderate heterogeneity for hyperactivity. This means that the findings were similar across the studies for the TDS, emotional symptoms and conduct, but varied considerably across studies for hyperactivity.

3.6. Exposure-effect relationships

To plot the statistically significant pooled estimates obtained from the meta-analyses, adjusted exposure-effect relationships were estimated, from a dataset that combined the RANCH, SEHS and WLSS, for the outcomes which showed statistically significant associations with aircraft noise exposure in the meta-analyses.

Fig. 5 shows that the continuous reading Z-score decreases as aircraft noise at school increases: reading Z-scores begin to fall below average (indicated by a Z-score of 0) at around 55 dB $L_{Aeq,16h}$. Fig. 6 shows that the predicted probability of having a well below or below average reading score increases as noise exposure increases. Post-hoc analyses showed that exposure to aircraft noise greater than 55 dB was associated with a doubling of odds for having a well below or below average reading score (41–45 dB OR = 0.40 95%CI 0.04 to 3.32; 46–50 dB OR = 1.69 95%CI 0.84 to 3.41; 51–55 dB OR 1.25 95%CI 0.61 to 2.39; 56–60 dB OR = 2.55 95% 1.24 to 5.22; 61–65 dB OR = 2.06 95% 1.08 to 3.93; >66 dB OR = 1.95 95% 0.94 to 4.03). Fig. 7 shows that the continuous SDQ hyperactivity score increases as aircraft noise at school increases: across the range of exposure hyperactivity scores increase by less than 1 (on a scale of 0–10). Supplementary Table 1 provides the raw data underlying these graphs to aid use in future health impact assessment (National Institute for Public Health and the Environment (RIVM), 2019).

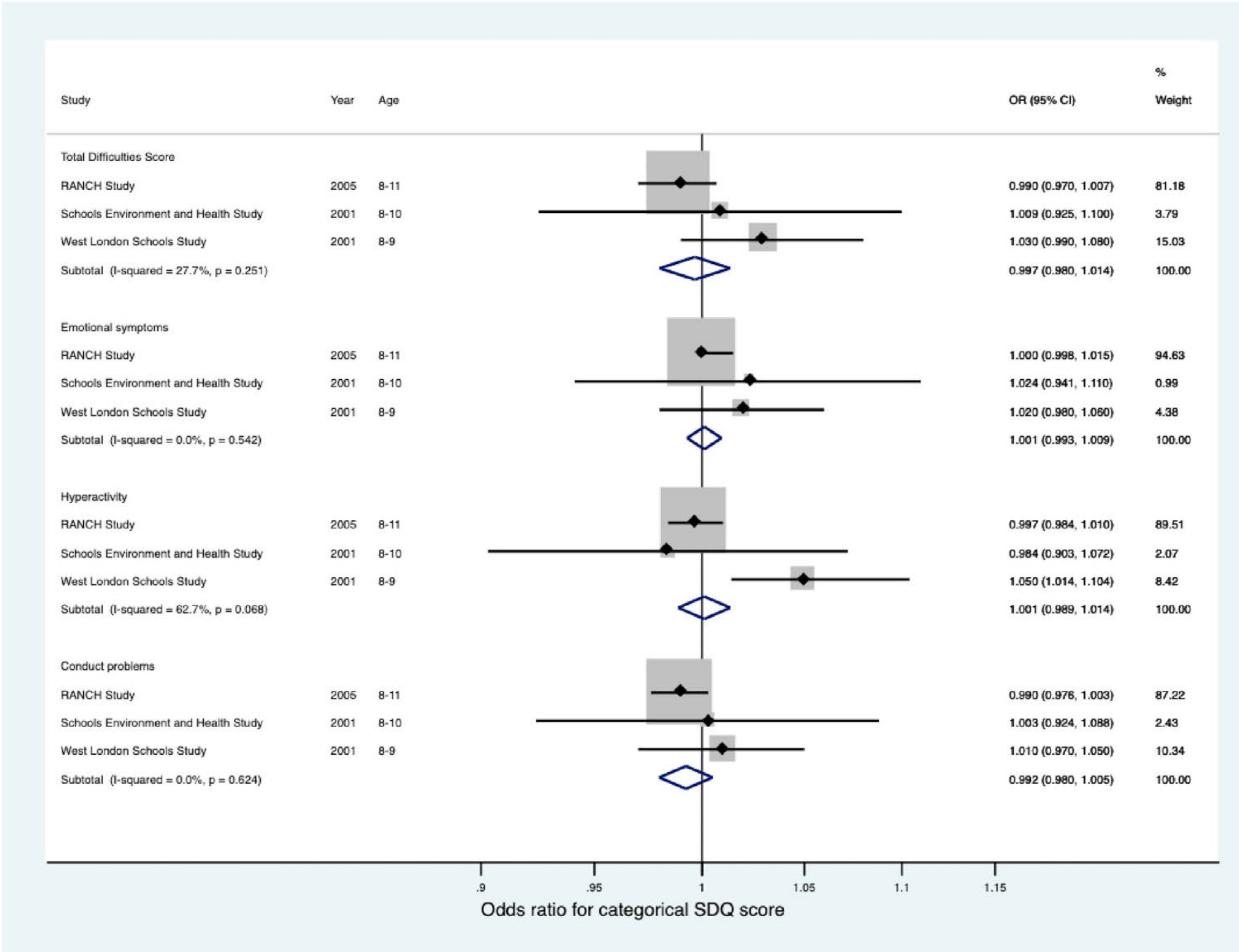

Fig. 4. Forest plot showing the association of a 1 dB increase in noise exposure at school ($L_{Aeq,16h}$) on categorical total difficulties score, emotional symptoms score, hyperactivity score and conduct problems score from the SDQ for the RANCH study, the SEHS, and the WLSS.

4. Discussion

4.1. Overview of findings

The aim of this study was to derive pooled estimates for the effect of aircraft noise exposure at school on children's cognition and psychological health for use in HIA. This study has conducted analyses of three methodologically similar studies conducted in London, the Netherlands, and Spain between 1996 and 2005, finding that a 1 dB estimate in aircraft noise exposure at school was associated with a statistically significant −0.007 (95%CI -0.012 to −0.001) decrease in reading score and a 4% increase in odds of scoring well below or below average on the reading test. The analyses also found that a 1 dB increase in aircraft noise exposure at school was associated with a 0.017 (95%CI 0.007 to 0.028) increase in hyperactivity score: however, this effect was not replicated in the analyses of being borderline or a case for hyperactivity. The exposure-effect relationships suggest that exposure to aircraft noise exposure >55 dB $L_{Aeq,16h}$ at school could be a threshold effect for effects on children's reading comprehension. Above this level reading comprehension starts to fall below average and the odds of having a well below or below average reading score increase. Whilst small in magnitude, these pooled effects have public health significance, given the range of exposure to aircraft noise in the population (European Environment Agency, 2020) and the importance of cognitive development and psychological health for life chances (Hale & Viner, 2018; Henderson, Richards, Stansfeld, & Hotopf, 2012; Kuh & Ben-Shlomo, 2004; Veldman, Reijnveld, Ortiz, Verhulst, & Bultmann, 2015).

The results of the categorical and continuous analyses suggest no effect of aircraft noise on conduct disorder symptoms, or emotional symptoms or TDS. These findings need replicating in further studies, and we consider that, as is the case for several previous systematic reviews, the evidence for effects of environmental noise, and in this case aircraft noise, on children's psychological health remains equivocal (Clark et al., 2020; Clark & Paunović, 2018b).

Recent systematic reviews of the effects of aircraft noise on cognition and psychological health highlight the methodological difficulties of undertaking statistical meta-analyses in this field despite an increasing evidence base (Clark et al., 2020; Clark & Paunović, 2018a, 2018b). Study variation in terms of how noise is characterised (e.g. in 1 dB or 10 dB increments versus high/low noise categorisation using different thresholds), as well as outcome assessment (e.g. the measure used and whether analysed continuously or categorically), adjustment for confounding factors, and level of detail reported in the publication has had a serious impact on the ability to undertake meta-analyses. This has limited most recent systematic reviews using the GRADE methodology (Guyatt et al., 2008) to provide an overview of the studies available and a narrative assessment of the strength of the evidence, with little quantification of the effects across studies. This paper presents the first quantitative meta-analysis of effects for aircraft noise on reading comprehension and psychological health.

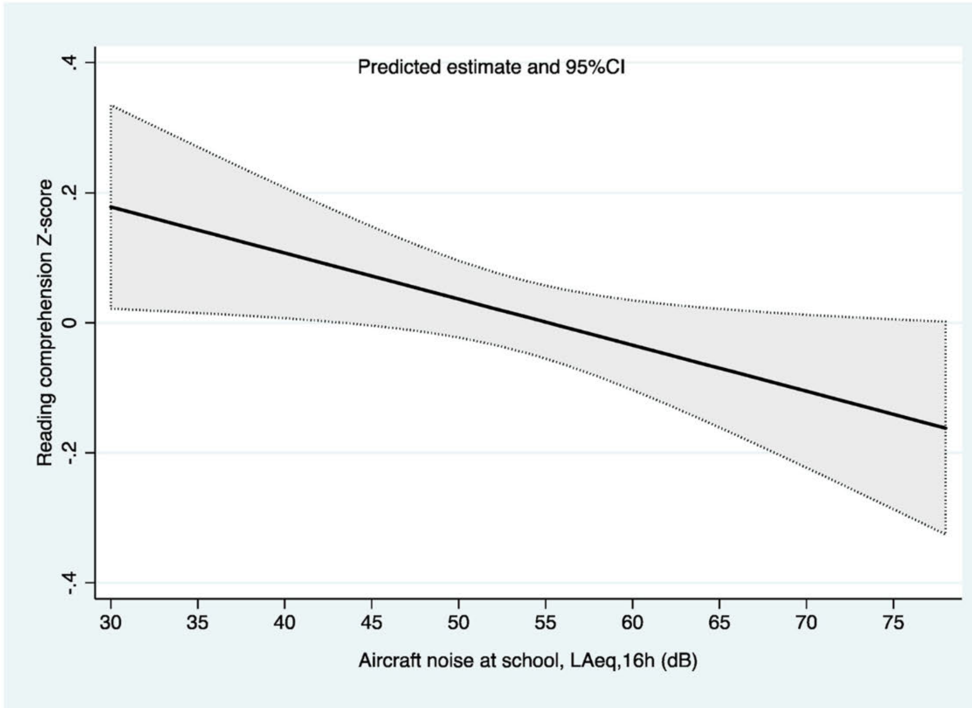

Fig. 5. Exposure-effect relationship of the adjusted association of aircraft noise exposure at school ($L_{Aeq,16h}$) on reading comprehension Z-score for the combined data from the RANCH study, the SEHS, and the WLSS.

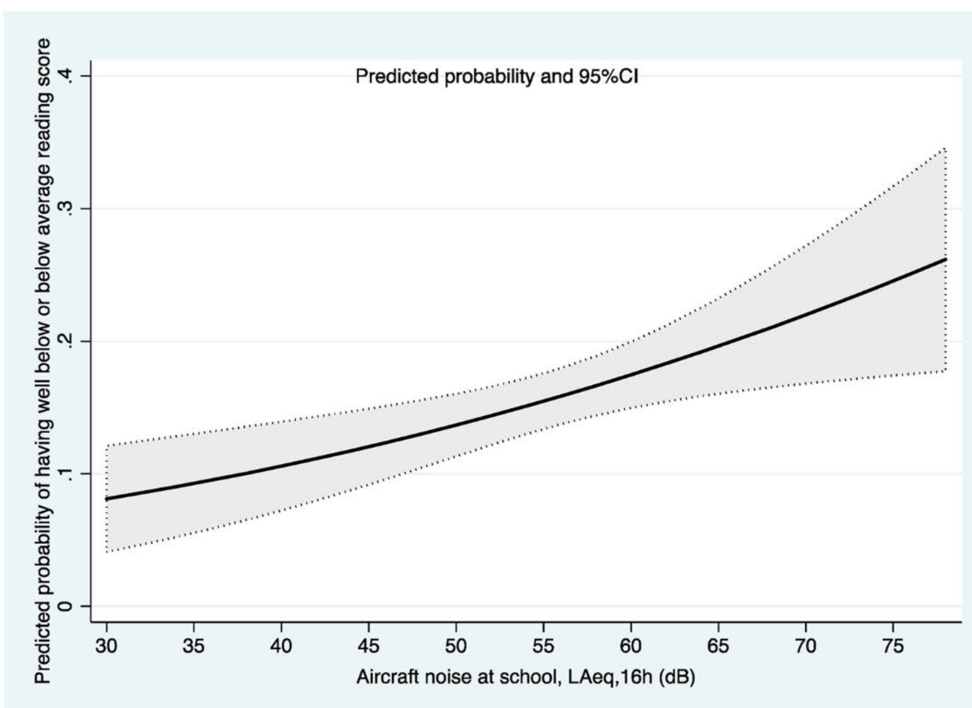

Fig. 6. Exposure-effect relationship of the adjusted association of aircraft noise exposure at school ($L_{Aeq,\ 16h}$) on scoring well below or below average on the reading test for the combined data from the RANCH-UK study, the SEHS, and the WLSS.

4.2. Comparison with previous evidence for reading comprehension

Previous narrative systematic reviews have indicated harmful effects of aircraft noise for reading comprehension (Clark et al., 2020; Clark & Paunović, 2018a). The pooled estimate from the current study of a −0.007 (95%CI -0.012 to −0.001) decrease in reading comprehension Z-score for the three studies for a 1 dB increase in aircraft noise is comparable to that previously found in the RANCH study for the pooled UK, Netherlands and Spanish data sets (β −0.008 95% CI-0.014 to −0.002) (Clark et al., 2006). The odds of scoring well below or below average on the reading test increased by 4% (95%CI 1%–6%) for a 1 dB increase in aircraft noise at school. However, it should be acknowledged

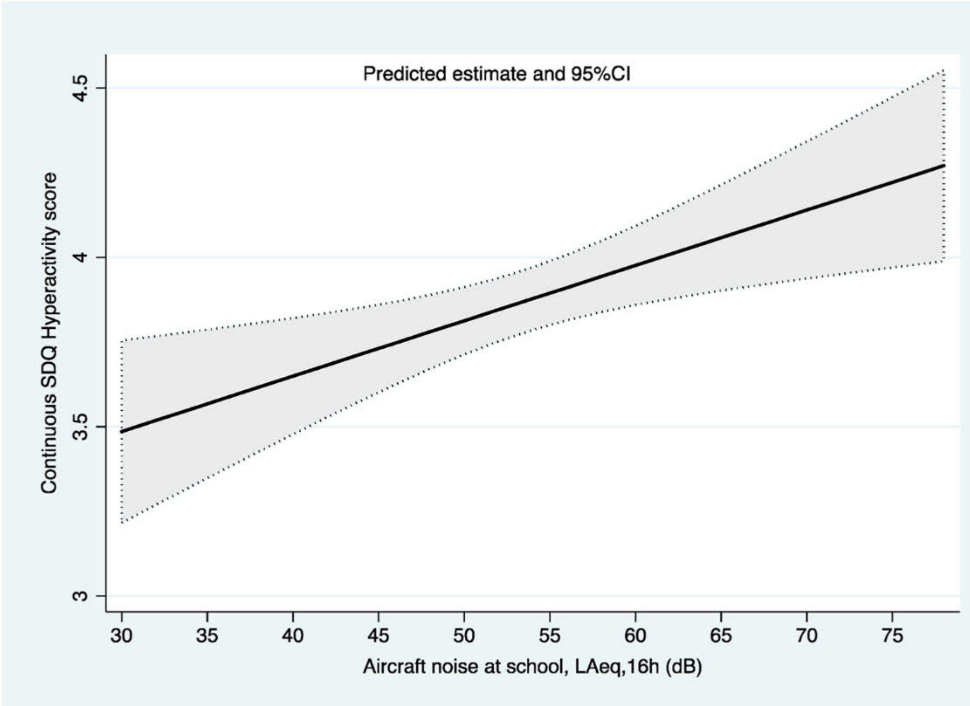

Fig. 7. Exposure-effect relationship of the adjusted association of aircraft noise exposure at school ($L_{Aeq,16h}$) on continuous SDQ hyperactivity score for the combined data from the RANCH study, the SEHS, and the WLSS.

that the similarity of effect size across studies may be an artefact of the similarity of methods used across the studies included in the meta-analysis. These effects are estimated for a 1 dB interval, so for example, and as the relationship is linear, a 10 dB increase in aircraft noise at school would be associated with a 40% increase in odds of scoring well below or below average on the reading test. It should be noted that aircraft noise effects on reading comprehension are generally thought to be small in magnitude (Clark et al., 2006), however, such effects could have important public health implications if a large proportion of the population were exposed and/or if the effects were cumulative or additive over the course of a child's education (Clark et al., 2012). The effects are also likely to disproportionately impact those experiencing inequality. The studies included in this meta-analysis cannot speak to the long-term impact of aircraft noise at school on children's learning. Longitudinal studies examining the effects of environmental noise exposure at school during different time-periods and across childhood on the trajectories of children's learning remain a research priority (Clark and Paunović, 2018a).

The RANCH-UK follow-up study of participants six years later in secondary school, aged 15–16 years, was not included in the meta-analysis as it is a repeated sample of the original RANCH-UK sample. The RANCH-UK follow-up study estimated a −0.016 (95%CI -0.05 to 0.018) decrease in reading comprehension Z-score for a 1 dB increase in aircraft noise. This larger effect could represent the cumulative influence of aircraft noise exposure at school throughout a child's education, however, it is difficult to say whether this truly represents a larger effect in secondary school or is an artefact of the study which only identified a trend and lacked statistical power (Clark et al., 2013). Unfortunately, there are currently no other studies that assess the effects of aircraft noise on cognition in secondary school students to be able to untangle this issue further.

The effect of aircraft noise on reading comprehension, which is a good marker for children's general cognitive ability, and which influences subsequent attainment and life chances, is now well established and the research focus needs to shift to evaluating interventions to ameliorate these effects in school environments. To date, there is limited evidence available (Bronzaft, 1981; Hygge et al., 2002; Sharp et al., 2014). A study of 6000 schools exposed between the years 2000–2009 around 46 United States airports, (exposed to Day-Night-Average Sound Level of 55 dB or higher) found that the effect of aircraft noise on children's learning disappeared once the school had sound insulation installed, supporting policies regarding the insulation of schools that may be exposed to high levels of aircraft noise (Sharp et al., 2014). A study of railway noise abatement also demonstrated improved standardised test scores (Bronzaft, 1981). A study of sound-field systems in the classroom, which project the teacher's voice failed to find any effect on children's cognitive abilities six-months after the installation of the systems (Dockrell and Shield, 2012) but this sample was not exposed to high levels of environmental noise.

4.3. Comparison with previous evidence for psychological health

In terms of the strength of the evidence, the findings of the current paper agree with the conclusions of the previous systematic reviews conducted to inform the World Health Organization's updated Environmental Noise Guidelines for the European Region (WHO, 2018), that there was low quality evidence for a harmful effect for hyperactivity and low quality evidence for no effect for conduct and emotional disorders.

The findings of the current meta-analyses for the effects of aircraft noise on the SDQ contrast with those from a recent meta-analysis which estimated a 10 dB increase in road traffic noise was associated with a 11% increase in odds for hyperactivity and a 9% increase in odds for TDS based on estimates from three studies from Germany, Denmark and Korea (Schubert et al., 2019). The current paper found an effect of aircraft noise on hyperactivity scale scores but not on odds for hyperactivity; nor did it find an effect for TDS. These differences may represent source-specific findings or may be an artefact of the analyses, as both meta-analyses analyse a sub-set of the available evidence due to methodological limitations of pooling estimates. Overall, across the meta-analyses currently available similar effect sizes are being observed but the types of psychological ill-health outcome where effects are found is not always consistent or comparable; effects also vary by type of noise exposure. Where effects are observed on psychological health these are also of a small magnitude and reflect an increase in psychological symptoms rather than a shift to clinical psychological illness, per se (Stansfeld & Clark, 2019). However, population health could be impacted by these types of increases in symptoms if exposure is widespread; if effects are cumulative or additive across childhood; and given the recurring nature of psychological ill-health across the lifecourse (Clark, Rodgers, Caldwell, Power, & Stansfeld, 2007). Longitudinal studies of exposure and trajectories of psychological health across childhood are needed to further clarify the evidence. There is clearly a need for further primary research studies to feed into future meta-analyses, as well as the need to try and incorporate more of the evidence already available into meta-analyses which would require co-ordinated reanalyses. There is also a need for studies to examine the pathway for effects of noise on psychological health as the effects may not be direct. Noise annoyance can cause stress responses which could also influence psychological health in the longer-term (Stansfeld & Clark, 2019). Further, noise could act as an additional stressor and interact with other environmental and psychosocial stressors to influence psychological health (Evans & De France, 2021). The possibility of further confounding by air quality remains, as this has also been shown to be associated with children's cognition and mental health (Forns et al., 2017; Newman et al., 2013; Stansfeld, 2015; Sunyer et al., 2015; van Kempen et al., 2012; Yolton et al., 2019).

In the interest of openness and being able to contribute to future meta-analyses, this paper has analysed both the continuous SDQ symptom scale scores as well as the categorical caseness SDQ score, which, based on an abnormal or borderline score, is more likely to reflect the presence of mental health disorders. However, the original SEHS, the WLSS, and the RANCH study analyses did not hypothesise effects of aircraft noise on SDQ caseness and these analyses are post-hoc. We might expect aircraft noise to be associated with symptom scores but not caseness. The stress-diathesis model is put forward to account for the effect of environmental noise on psychological health, where exposure increases arousal and chronic exposure leads to chronic physiological change and subsequent health effects (Babisch, 2014; Stansfeld & Clark, 2019). Previous reviews have concluded that environmental noise predicts annoyance (Guski, Schreckenberg, & Schuemer, 2017), as well as psychological symptoms, but not clinically definable psychiatric disorder (Stansfeld & Clark, 2019), suggesting that noise exposure might be associated with milder conditions, such as those measured by symptom scales. For example, it has previously been hypothesised that aircraft noise might not cause hyperactivity per se but that it may make an existing tendency towards hyperactivity worse or more obvious (Stansfeld et al., 2009). This argument may also apply to other psychological health outcomes.

4.4. *Implications for health impact assessment*

This study, the first meta-analysis quantifying the effect of aircraft noise on reading comprehension enables reading comprehension to be taken into account in HIA. HIA focuses on estimating the health gains (e.g. employment, opportunities for physical activity) or health losses (e.g. effects on physical or mental health, social capital) associated with an environmental exposure (e.g. noise, air quality) or the development of a scheme as a whole (e.g. airport development, building a new railway) (European Environment Agency, 2020; National Institute for Public Health and the Environment (RIVM), 2018; NHSLondon Healthy Urban Development Unit, 2019). We recommend that reading comprehension be included in future HIAs in relation to noise exposure. In terms of the findings of the current study, HIA could apply either the continuous or categorical estimates for reading comprehension, which indicated an adverse effect of aircraft noise on reading comprehension. Stakeholders may find the categorical estimates have more face validity within local communities who might relate more easily to reading comprehension being 'well below or below average' compared with a decrease in a reading Z-score.

Given the equivocal findings for effects of aircraft noise on psychological health from this study, the implications for HIA need careful consideration. The statistically significant estimate for the negative effect of aircraft noise on the continuous hyperactivity score could be applied in HIA. This effect for hyperactivity was also observed in the original RANCH study analyses which included samples from the UK, the Netherlands and Spain (Stansfeld et al., 2009). At this point in time, until further meta-analyses can be conducted for effects of aircraft noise on TDS, emotional symptoms and conduct problems, quantification of these effects using meta-analyses remain uncertain and these outcomes should not be included in HIA.

4.5. *Strengths & limitations*

Limitations of the research include the smaller samples for the SEHS and the WLSS, however, the use of meta-analyses to pool these studies increases the statistical power of these smaller studies, which have often found trends for effects rather than statistically significant effects. However, the individual reanalyses of the SEHS and WLSS to estimate effects for the meta-analysis may still lack statistical power. The SEHS and WLSS were not designed to estimate effects of a 1 dB increase in aircraft noise but to compare high and low exposure. Historically, the studies have been carried out over a 9 year period from 1996 to 2005, during which time exposure assessment of aircraft noise improved. This has meant that for the earliest studies, SEHS and WLSS, we had to rely on the contour band data available at the time the studies were conducted to estimate exposure rather than exposure in 1 dB categories. We have conducted sensitivity analyses showing that the results do not change if we change the assumptions about where in the contour band the true exposure might lie, but exposure-misclassification remains a possibility. We did not have information about aircraft noise exposure at home available in two of the studies (SEHS, WLSS) so were unable to consider the further implication of aircraft noise exposure at home on the findings: previous analyses of the RANCH study found that aircraft noise at school and at home had similar effects on reading comprehension, but home exposure did not explain any additional impact (Stansfeld, Hygge, Clark, & Alfred, 2010). Only the RANCH study was able to take the co-exposure of road traffic noise into account and none of the analyses take air quality into account: both these exposure may alter the findings of the study (Clark et al., 2012). The meta-analysis is focused on three studies employing very similar methodologies, and does not include additional relevant papers that use different outcomes or methodologies (Connolly et al., 2019; Klatte et al., 2016; Seabi, Cockcroft, Goldschagg, & Greyling, 2012). Finally, the studies provide estimates adjusting for a slightly different set of confounding variables, but sensitivity analyses suggest this has had little impact on the findings of this paper.

Strengths of the research include advantages afforded by the shared methodologies across the three studies, which have enabled meta-analysis of estimates that adjust for a wide-range of relevant confounding variables. A further strength is the policy focus of the estimates, which have been specifically designed for application by health impact assessment practitioners and policy makers determining methodologies for the monetisation of noise and health impacts. These assessments are often the only line of defence for communities impacted by airport development in the decision making process. These analyses are designed specifically to be used by these audiences for this purpose.

5. Conclusions

Reading comprehension should be taken into account in HIA and monetisation methodologies. This is the first meta-analysis to quantify the pooled effect of aircraft noise at school on children's reading comprehension across studies. The analyses confirm existing evidence for effects of aircraft noise exposure on children's reading comprehension, and provides additional estimates for effects on scoring 'well below or below average' on the reading test. For effects on children's cognition, attention should now shift on the long-established need to evaluate and quantify the impact of interventions, particularly the sound insulation of schools on children's learning outcomes. The meta-analysis also confirmed an effect of aircraft noise on children's hyperactivity symptoms scores. Evidence for effects of aircraft noise on other aspects of children's psychological health remains uncertain. The results of the analyses for reading comprehension and psychological health are designed to inform policy and HIA in a wide-range of contexts.

The funding of the original studies is as follows

The Schools Environment and Health Study was funded by a consortium of local authorities and health agencies around Heathrow Airport and was submitted as a public report for the Terminal 5 Public Inquiry; the West London Schools Study was jointly funded by the Department of Health and Department of the Environment and Transport and the Regions (grant number: noise 403/26498); and the RANCH project was funded by the European Community (QLRT-2000-00197) under the 5th Framework programme under Key Action 1999:/C 361/06 "Quality of life and management of living resources". The RANCH project was co-funded by the Department of Environment, Food and Rural Affairs (United Kingdom); the Dutch Ministry of Public Health, Welfare and Sports, the Dutch Ministry of Spatial Planning, Housing and the Environment and the Dutch Ministry of Transport, Public Works and Water Management.

We thank all the pupils, parents and teachers who participated in these studies, as well as team members of the SEHS, WLSS and RANCH study.

Ethical approval

The Schools Environment and Health Study and the West London Schools Study: were approved by the joint University College London and University College London Hospital Committees on the Ethics of Human Research: Committee Alpha; the Hillingdon Health Agency Ethics Committee; and the Ealing, Hammersmith and Hounslow Heath Agency Ethics Committee.

The RANCH Study: in the United Kingdom, ethical approval was given by the East London and the City Local Research Ethics Committee, East Berkshire Local Research Ethics Committee, Hillingdon Local Research Ethics Committee and the Hounslow District Research Ethics Committee; in the Netherlands, by the medical ethics committee of TNO, Leiden and in Spain, by the CSIC Bioethical Commission, Madrid.

CRediT authorship contribution statement

Charlotte Clark: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Writing – original draft. **Jenny Head:** Conceptualization, Funding acquisition, original. **Mary Haines:** Conceptualization, Funding acquisition, original. **Irene van Kamp:** Conceptualization, Funding acquisition, original. **Elise van Kempen:** Conceptualization, Funding acquisition, original. **Stephen A. Stansfeld:** Conceptualization, Funding acquisition, original studies, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2021.101646.

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