Al Ministero dell'Ambientee della Sicurezza Energetica
Direzione Generale
Valutazioni Ambientali

Osservazioni:

PropostaProgetto Parco Eolico
Cod.MYTERNA N. 202303409
PUGLIA– RUVO DI PUGLIA e altri Comuni

Ilsottoscritto Pellegrini Raffaele trasmette, in allegato,

- le osservazioni prodotte dal dr. Di Virgilio Michele, biologo, dopo aver visionato la documentazione relativa alla procedura di Valutazione Impatto Ambientale;
- l'elenco di tutte le fonti consultate.

Distintisaluti.

Ruvodi Puglia lì 4/06/2024

RaffalePellegrini

All.c.s.

Al MINISTERO dell'AMBIENTE e
della SICUREZZA ENERGETICA

Direzione Generale valutazioni ambientali

OSSERVAZIONI
Proposta Progetto Parco Eolico
Cod. MYTERNA N. 202303409

REGIONE PUGLIA
Comune di RUVO DI PUGLIA  ed altri COMUNI

Il sottoscritto Di Virgilio Michele, nato l’11/09/1991 a Terlizzi e residente a Ruvo di Puglia (BA), biologo, dopo aver visionato la documentazione prodotta, evidenzia le criticità di seguito riportate.

In relazione agli effetti nocivi sulla salute si segnalano gli studi di eminenti medici come il dr. Robert  McMurtry (MD, FRCS, FACS), ex preside della facoltà di Medicina presso l’Università del Western Ontario che ha avuto, nel 1999, la prima Cameron Visiting a Health Canada – un lavoro che comportava la responsabilità di consigliare la linea di condotta al vice ministro ed al ministro della sanità del Canada.

Nel dicembre del 2003, venne nominato all’Health Council del Canada con Chair of thr Wait Times and Accessibility Work Group. Tra le altre, il dr. McMurtry è il sostituto vice ministro fondatore della Population and Public Health Branch di Health Canada. Nel 2002 egli fu nominato nella commissione Roy Romanov sul futuro di Health Care Canada come consigliere speciale del commissario Romanow.

Nella sua deputazione alla Commissione permanente sul disegno di Legge B-150, presentato all'Assemblea legislativa dell'Ontario, il dr. McMurtry ha dichiarato:

“Ci sono pervenute molte notizie di effetti nocivi sulla salute. All'inizio bisogna mettere in chiaro che non sono stati fatti studi sistematici ed epidemiologici sul terreno che dessero direttive autorevoli sul luogo di installazione delle turbine. In secondo luogo, non si sono condotti studi epidemiologici per stabilire la sicurezza o la dannosità delle turbine eoliche industriali. In breve, vi è una mancanza di prove. Perciò, fino a che un'informazione più autorevole sia disponibile è importante prendere in considerazione di casi riferiti e la serie di casi con effetti nocivi sulla salute che vengono alla luce".

Va messo in evidenza che, come per tutte le questioni di sanità pubblica, bisognerebbe prendere misure precauzionali per evitare il diffondersi del rischio alla salute secondo le parole del dr. McMurtry: "Quando sussiste l'incertezza e il benessere e la salute delle persone sono potenzialmente a rischio, è certamente appropriato invocare il principio di precauzione".

L'industria eolica spesso afferma che "non vi è evidenza scientifica di pubblicazioni a comitato di lettura che dimostri l'impatto nocivo sulla salute umana causato dalle turbine eoliche". (Questa affermazione è presa direttamente dai progetti di costruzione di turbine eoliche presentate all'approvazione).

Tuttavia, in una lettera datata 6 agosto 2009 scritta dall'Health Canada Safe Environments Program (Halifax), Allison Denning, coordinatrice del Regional Environmental Assessmet Health Canada, Atlantic Region, aveva fatto notare quanto segue:

"Health Canda consiglia di rivedere questa affermazione segnalando che esistono articoli scientifici con comitato di lettura indicanti un possibile effetto nocivo sulla salute umana provocato dalle turbine eoliche. In realtà esistono articoli scientifici con comitato di lettura che segnalano la possibilità che le turbine eoliche possano avere un impatto nocivo sulla salute delle persone".

Alcune delle più importanti autorità mediche mondiali hanno già dato alcuni avvertimenti. Nel seguente elenco se ne citano alcuni di essi:

1) The National Institutes of Health (NIH). Nel 2008, l'NIH (parte dell'US Department of Health and Human Services) aveva così messo

in guardia:

“Indubbiamente l'energia eolica produrrà rumore, il quale aumenta lo stress, che, a sua volta, aumenta il rischio di malattie cardiovascolari e cancro. (Enviromental Helath Perspectives, vol. 116, pg. A237-238, 2008).

2) Accademia Nazionale Francese di Medicina. Nel 2006, l'Accademia Nazionale Francese di Medicina aveva presentato un rapporto che conclude così:

“Gli effetti nocivi del suono prodotto dalle turbine eoliche non sono stati sufficientemente accertati. Il suono emesso dalle pale è a bassa frequenza, la quale si diffonde facilmente e varia a seconda del vento e costituisce un rischio permanente per coloro che vi sono esposti. L'Accademia raccomanda la costruzione di turbine eoliche al massimo di 1,5 km dalle abitazioni” (Chouard, C-H. Le retentissement du fonctionnement des èoliennes sur la santè de l’homme. Panorama du Mèdicin, 20 marzo 2006).

3) Minnesota Department of Health. Il 22 maggio 2009, il Minnesota Department of Health ha pubblicato un rapporto sulla valutazione dell'impatto sulla salute del rumore provocato dalle turbine eoliche e sulle vibrazioni della bassa frequenza. Le conslusioni facevano notare che le turbine eoliche generano un largo spettro di rumore a bassa intensità. La bassa frequenza può disturbare le persone nelle loro case, specialmente di notte.

   “La rimostranza più comune presente nei vari studi sugli effetti delle turbine eoliche  sulle persone è l'impatto sulla qualità della vita. Insonnia e cefalea sono i disturbi più comunemente osservati e sono altamente correlati con i sintomi di fastidio. I disturbi sono più verosimili quando le turbine sono visibili o quando vi è lo sfarfallamento dell'ombra. La maggior parte dell'evidenza disponibile suggerisce  che gli effetti sulla salute riferiti sono connessi alla bassa frequenza udibile e a un aumento dei livelli di rumore esterno superiori a 35 dB”.

   “In generale il rumore della bassa frequenza prodotto dalla turbina eolica non è facilmente percettibile al di la di ½ miglio”

“Nella mia qualità di esperto, secondo la mia conoscenza della fisiologia del sonno e dall'esame della ricerca disponibile, non ho alcun dubbio che il rumore prodotto dalle turbine provochi disturbi del sonno e cattiva salute". (dr. Christopher Hanning)

Il dr. Hanning ha inoltre dichiarato: "Non vi è alcun dubbio che gruppi di turbine eoliche industriali ("wind farms") producano rumore sufficiente per disturbare il sonno e danneggiare la salute di coloro che vivono nelle vicinanze . Egli ha osservato che "le famiglie le cui abitazioni si trovavano a circa 900 metri dalle turbine, col tempo, le abbandonarono a causa dei disturbi del sonno e cattiva salute".

Hanning attira l'attenzione sul fatto che "con un sonno inadeguato non è stato solo associato alla fatica, alla sonnolenza e a un deterioramento cognitivo, ma anche ad un aumento nel rischio di obesità, una compromissione nel test di tolleranza al glucosio (rischio di diabete), pressione sanguigna alta, malattia cardiaca, cancro e depressione.

Hanning analizza e contesta l'accettabilità di parecchi studi commissionati dall'industria a causa delle loro metodologie viziate e di ricercatori che lavoravano al di fuori della loro area di competenza.

UN BREVE ESAME DELLA LETTERATURA BASATA SULLE PROVE

Il rapporto del giugno 2009 su "Sleep disturbance and wind turbine noise" del medico inglese Cristopher Hanning (Bsc, MB, BS, MRCS, LRCP, FRCA, MD) basata sulle prove. Il rapporto può essere consultato in formato pdf all'indirizzo http://www.windaction.org/documents/22602.

Le credenziali e l'esperienza del dr. Hanning sono fuori discussione. Egli è uno dei più importanti specialisti del rumore, dei disturbi del sonno e delle sue conseguenze sulla salute. Il dr. Hanning ha fondato e dirige il Leicester Sleep Disorders Service, uno dei più grossi reparti in funzione da lungo tempo del Regno Unito. Il suo rapporto si conclude così:

"Nell'esaminare le prove ho trovato che, da un lato, si osserva un gran numero di casi di disturbi del sonno e, in alcuni casi, una cattiva salute causata dalle turbine eoliche confermata da un certo numero di rapporti di ricerca che tendono a confermare la validità di rapporti aneddotici e costituiscono una base ragionevole per le proteste. Dall'altra parte, abbiamo rapporti dell'industria e del governo redatti male e che cercano di dimostrare che non ci sono problemi. Io trovo questi ultimi poco convincenti".

Negli Stati Uniti, un altro medico con una reale esperienza clinica è la dott.ssa Nina Pierpont, che si occupa di pazienti con sindromi da turbine eoliche (Nina Pierpont, MD, PhD, "Wind Turbine Syndrome: A report of a Natural Experiment, 2009). Il suo lavoro è uno studio caso-controllo molto dettagliato e rivisto su 10 famiglie nel mondo con disturbi così gravi provocati dal rumore delle turbine da dovere abbandonare le loro case, nove di questi definitivamente. La potenza delle turbine oscillava da 15 a 3 MW, con distanze fra 305 e 1500 m. Il gruppo era composto da 21 adulti, 7 adolescenti e 10 bambini, 23 dei quali vennero intervistati. Anche se si tratta di un gruppo altamente selezionato, l'abilità di esaminare i sintomi prima, durante e dopo l'esposizione al rumore delle turbine gli dà una solidità raramente osservata in studi caso-controllo similari. Il soggetto descriveva i sintomi della sindrome da turbina eolica e confermava la loro assenza prima dell'entrata in funzione delle turbine e la loro sparizione quando non vi era più esposizione.

La dr.ssa Pierpont fornisce una prova irrefutabile che questi sintomi sono prodotti dal suono a bassa frequenza emesso dalle turbine eoliche e propone meccanismi fisiologici molto plausibili per spiegare il legame fra l'esposizione alle turbine e i sintomi stessi. Particolarmente preoccupanti erano gli effetti sui bambini, ragazzi in età scolare e liceali. Sono stati osservati cambiamenti nei ritmi del sonno, sul comportamento e nei risultati scolastici durant: 7 su 10 bambini avevano avuto un calo nei risultati scolastici durante l'esposizione al rumore delle turbine, e un recupero quando l'esposizione era cessata. In totale 20 dei 34 soggetti studiati avevano riferito di aver avuto problemi di concentrazione e di memoria.

Un lavoro pubblicato sulla vibrazione prodotta dalla bassa frequenza delucida il lavoro della dr.ssa Pierpont. Esso si intitola "Research from Neuroscience Letters 444 (2008) 36-41" ed è frutto dei ricercatori medici McAngus Ross, Sally M. Rosengren, James G. Colebatch: un lavoro che conferma l'opinione della dr.ssa Pierpont secondo la quale il rumore a bassa frequenza e quello dell'infrasuono possono danneggiare l'apparato vestibolare dell'orecchio interno. Questa ricerca spiega l'affermazione che ciò che non puoi sentire può nuocere.

Nel marzo 2009, il dr. Michael Nissenmbaum del Nothern Maine Medical Center ha presentato il suo studio alla Maine Medical Association. I risultati di questo studio suggeriscono che i suoi pazienti soffrono di gravi problemi di salute dipendenti dallo sfarfallamento dell'ombra e dall'emissione di rumore proveniente dalle turbine L'insorgere dei sintomi comprende: disturbi del sonno, cefalee, sensazione di instabilità, variazioni di peso, aumento della pressione sanguigna.

Il dr. Nissenbaum ha scritto: "Vi sono parecchie questioni che devono essere risolte. È logico richiedere che devono essere risolte. È logico richiedere una moratoria, a meno che non decidiamo rapidamente di adottare i rigorosi standard europei e australiani. Altrimenti se lo Stato è incapace di agire in maniera responsabile su questo problema, è come se rinunciasse a proteggere la salute pubblica, il che significa che alla gente rimarrebbero poche opzioni diverse dal trovare un rimedio rivolgendosi al tribunale".

In Giappone, nel febbraio 2009, si sono riscontrati 70 casi di effetti nocivi sulla salute causati dalle turbine eoliche. I giapponesi la chiamano "Malattia da Turbina Eolica". Finora più di 70 persone che abitano vicino alle turbine hanno dichiarato di essere in cattiva salute. Di questi fanno parte gli abitanti di Ikata, nella Prefettura di Eihme; Higashi-Izu, nella Prefettura di Shizuoka; Toyohashi, nella Prefettura di Hyogo.

In Ontario, sia i ricercatori che le vittime hanno riscontrato un mutamento nelle condizioni di vita e una cattiva salute. I disturbi del sonno sono i problemi più comuni. Altri sintomi sono: problemi dell'orecchio interno, implicazioni cardiache quali aritmie e palpitazioni, cefalee, disturbi cognitivi e di umore, ipertensione.

Nella sua revisione della letteratura "Low Frequency Noise and

Infrasound. A literary comment" (2006), il dr. Ivan Buxton nota:

- vi è un gran numero di articoli scientifici che fanno riferimento agli effetti della frequenza infrasonica e della vibrazione degli essere umani. Risulta evidente da questi lavori che l'effetto del rumore a bassa frequenza è strettamente connesso ai rischi cardiovascolari e agli effetti cronici endocrini, incluso un aumento della produzione di cortisolo. Come indicato da Harlow et al. (1987), un cortisolo cronicamente elevato può avere un impatto negativo sulla produzione animale, riducendo l'aumento di peso e influenzando negativamente gli animali in cattività ( Van Mourik e Steemasiak, 1984; Van Mourik et al., 1985) e una diminuzione della produzione di anticorpi significa inibire o sopprimere la capacità di resistenza dell'organismo alla malattia (Roth, 1984; Jensen e Rasmussen, 1970; Huber e Douglas, 1971; Revillard, 1971; Paape et al., 1973; Hartman et al., 1976; Stein et al., 1976).

- "Questi effetti, specialmente se sono cronici, possono presentarsi sotto forma di malessere crescente, malattia e morte; una diminuzione della produzione animale (Knight e Cole, 1991; Anderson e Keith, 1980); e – risultato finale – una diminuzione della popolazione in una popolazione di animali selvatici (Anderson e Keith 1980).

  Di seguito, un elenco di alcuni studi che hanno fornito una spiegazione delle cause dei sintomi osservati fra coloro affetti dagli effetti nocivi delle turbine:

i) *Selected Health risks caused by long-term, whole body vibration response*, Seidel H. Federal Inst. Of Occupational Health, Berlin (*The American Journal of Medicine*, 1993 Apr 23(4); 589-604);
ii) *Characterising the effects of airborne vibration on human body vibration response*, Smith S.D. Air Force Research Lab. Wright – Patterson AFB, USA (*Aviation. Space Environment Med.* 2002 Jan. 73(1); 36-45);
iii) *Low Frequency noise enhances cortisol amoung noise sensitive subjects during work performance*, Kerstin Person-Waye, J. Bengtsoon, R. Rylander, F. Hucklebridge, P. Evans, A. Clow, Dept. Environmental Medicine, University of Gothenburg (*Life Science*

2002 Jan. 4; 70(7), 754-58);

iv) *Noise induces Endocrine Effects and Cardiovascular Risks*, H. Ising, W. Babish, B. Kruppa, Federal Environmental Agency, Inst. Of Water, Soil & Air hygiene, Berlino (Noise Health, 1999 1(4); 37-48);

v) *Coping with stress; Neuroendocrine Reactions and implications for Health*, U. Lundberg, Dept of Psychology, Stockholm (*Noise Health* 1999, 1(4); 67-74);

vi) *Possible Health Effects of noise induced cortisol increase*, M. Spreng, Dept. of Physiology, Univ. Erlangen, Germany (*Noise Health* 2000; 2(7), 59-64);

vii) *Acute and chronic endocrine effect of noise*, H. Ising, C. Braun. Review of the research conducted at the Inst. For Water, Soil & Air Hygiene, Berlin (*Noise Health* 2000; 2(7), 7-24).

Va inoltre messo in evidenza che vi è un largo consenso sul fatto che le turbine eoliche creano un rumore invadente e vi sono parecchi studi sottoposti a comitati di lettura che descrivono gli effetti nocivi del rumore sulla salute. Ad esempio:

1) World Health Organization. *Noise and Sound*, Bergland et al., 2000;
2) Health Council of the Netherlands (HCN). *The Influence of Night time Noise on Sleep and Health*, 2004;
3) Human Rights section 9, EU, June 2007.

Secondo il dt. Buxton, “l'ambito delle frequenze è stato registrato in molti di questi studi e il risultato complessivo sembra sempre dipendere dal tempo di esposizione combinato con livelli di dB e Hz. Sono necessari solo pochi secondi perché un suono di molto bassa frequenza e alto livello dB provochi gravi problemi.

“Il suono a bassa frequenza può viaggiare su lunghe distanze e penetrare negli edifici e nei veicoli e non diminuisce in modo rilevante le sue proprietà quando cambia l'elemento, come ad esempio dall'aria al tessuto. Ciò avviene perché, al contrario degli ultrasuoni, esso viaggia meglio in *bande* e questo è dovuto alla tendenza delle onde del suono a bassa frequenza a viaggiare in“*linea retta*”.

## EFFETTI DELLE TURBINE EOLICHE SULLA FLORA E FAUNA SELVATICHE, BESTIAME E ANIMALI DOMESTICI

Prove sempre in aumento dimostrano che gli animali sono affetti ancora più gravemente degli essere umani dal rumore di bassa frequenza e dalle vibrazioni provenienti dalle turbine industriali. Questo fenomeno ha delle serie implicazioni sugli impegni presi di proteggere le specie in pericolo e minacciate dalla sempre maggiore restrizione degli habitat naturali sensibili. Esso rafforza e aumenta le cautele sui problemi della salute umana già citati qui sopra.

Lo stato di confusione provocato dalle emanazioni può condurre all'impossibilità di cacciare, di auto difendersi e, in ultimo, di sopravvivere. A titolo di esempio, i serpenti, che si affidano in larga parte alla loro percezione delle vibrazioni, sono particolarmente sensibili ai disturbi dell'habitat provocati dagli sviluppi industriali.

L'inquinamento provocato dal rumore di alte frequenze può essere la causa dell'effetto catastrofico che le turbine stanno provocando nei pipistrelli, una specie di importanza capitale nell'equilibrio naturale. Invadendo una larga area di habitat con un inquinamento da rumore estraneo vi saranno ovvie ripercussioni sulla sopravvivenza di specie che dipendono dalle speciali caratteristiche di questi rifugi unici. Come osservato dai biologi, questo fenomeno è la causa dell'abbandono permanente di questi luoghi da parte delle specie di cui sopra.

Similmente lo sfarfallamento delle ombre e la sua diffusa emissione di rumore è un altro fenomeno che segnala pericolo alle specie selvatiche. Entrambe queste perturbazioni causano confusione e allontanamento, contribuendo all'abbandono dell'habitat così coinvolto. Quando queste perturbazioni colpiscono una specie già minacciata, forzandola ad abbandonare uno degli ultimi habitat ancora adatti, le conseguenze possono essere catastrofiche. Occorre fare presente che l'ecologia all'interno di ogni Sistema dell'Eredità Naturale (Natural Heritage System) è completamente interconnessa e che gli effetti apparentemente insignificanti hanno ripercussioni importanti a causa della inter-dipendenza di tutte le specie dentro il sistema.

Il dr. Buxton ha così concluso:

“C'è una questione da risolvere quando animali terrestri e specie di acqua dolce sono esposte a rumori di basse frequenza. A causa dei limiti del nostro udito potrebbe essere facile supporre che rumori al di fuori del nostro intervallo di ricezione uditiva non esistono e non debbano quindi creare preoccupazione. Eppure sia suoni non udibili molto alti che molto bassi possono essere nocivi per noi come per altri animali con intervallo di percezione uditiva simile ma non identico al nostro”.

“Altri esseri viventi hanno più bassi livelli di accettazione che la specie umana in quanto la loro sopravvivenza dipende maggiormente dall'istinto e dall'interpretazione di suoni non abituali come segnali di pericolo. Bastano pochi secondi perché un suono di bassa frequenza e alto livello di decibel induca seri problemi. C'è ragione di ritenere che effetti simili si verifichino anche per animali selvatici se esposti al suono per periodi abbastanza lunghi. Si deve presumere che non appena si sentono a disagio si allontanino dalla zona: è un fenomeno più propriamente descritto come *disturbo e dislocazione*, che nel caso di specie protette va contro la legislazione pertinente.

“L'esame di studi condotti su animali in laboratorio ha chiarito che essi vanno regolarmente incontro a deformità, danno e deterioramento delle condizioni. Gli animali erano legati e soggetti a esposizioni di varie ore al giorno a livelli fra moderati e alti di LFN (rumore a bassa frequenza) e ultrasuoni. Similmente, i pesci e gli organismi acquatici costretti entro bacini e laghi sono certamente impossibilitati a fuggire quale che sia l'intensità o la durata del suono”.

Riguardo agli esempi dell'effetto del rumore sugli animali, il dr. Buxton cita: la riduzione della deposizione di uova in pollame domestico; capre con produzione di latte ridotta; maiali con eccessiva secrezione ormonale e ritenzione di acqua e sodio; pecore e agnelli con aumentata frequenza cardiaca; disturbi respiratori e riduzione dell'alimentazione.

## PERDITA DELL'HABITAT. STUDI EUROPEI

Gli studi decennali condotti da biologi europei hanno fornito un incremento di prove sugli effetti delle turbine eoliche sulla flora e fauna selvagge.

Gli scienziati hanno raggiunto la conclusione che l'installazione di turbine eoliche vicino a grandi arre protette ha un effetto distruttivo duraturo ed irreversibile su questi habitat. L'effetto è cumulativo e più a lungo le turbine rimangono “in loco” più tale effetto aumenta.

## BESTIAME

Degli allevatori dell'Ontario avevano notato problemi di salute nel loro bestiame, iniziati poco dopo l'installazione delle turbine. La conoscenza dei risultati della ricerca citata dal dr. Buxton (vedi sopra), che dimostra l'esistenza di effetti endocrini e cardiovascolari dovuti al rumore, convalida certamente i sintomi osservati dall'allevatore dell'Ontario Ross Brindley che abita vicino alla zona delle turbine eoliche site nei pressi di Goderich. Secondo il rapporto del dicembre 2008 pubblicato sulla rivista *Better Farming,* il suo bestiame si comportava in modo aggressivo e bizzarro come: “vitelli appena nati che tiravano calci, parto con prolasso, perdita di peso, diminuzione della fertilità, una percentuale alta di mastiti, vitelli nati deformi e una grande incidenza di nati morti”. Dopo una cessazione di attività causata dai problemi insorti nella sua mandria di manzi, Brindley ha intentato un processo a Hydro One Networks Inc. e a Edmonton Power Corporation (EPCOR).

## CAPRE

Nello stesso contesto, la BBC ha recentemente riferito che 400 capre erano morte a Taiwan dopo che erano state costruite otto turbine eoliche vicino ai loro pascoli. Le capre apparivano scarne e non mangiavano. L'allevatore racconta di essere uscito una notte e di aver visto che le capre erano tutte su quattro zampe e non dormivano. The Council of Agricolture ha sospettato che il rumore sia stato la causa della morte delle capre, avvenuta per mancanza di sonno. Perciò la compagnia elettrica Taipower si è offerta di pagare in parte la ricostruzione di un'altra fattoria altrove.

VALUTAZIONE DEL RUMORE DELLE TURBINE

Il dr. Hanning contesta l'affermazione secondo cui la continua esposizione al rumore dà assuefazione: “Si è spesso affermato che un'esposizione continua al rumore dà assuefazione. Un piccolo studio recente (Pirrera et al., 2009) sugli effetti del rumore del traffico sulla mancanza di sonno suggerisce il contrario”.

Egli fa notare l'errore di utilizzare livelli medi del rumore, oppure di misurare la velocità del vento a un'unica bassa altitudine.

Studi di abitanti che vivono in prossimità di turbine eoliche industriali mostrano livelli alti di disturbi del sonno e senso di fastidio. Un'indagine condotta nel 2005, in Francia, su 200 abitanti che vivono nel raggio di 1 km. da un gruppo di 6 turbine di 9 MW rivela che il 27% di questi avevano dichiarato di essere disturbati dal rumore durante la notte (Butre et al., 2005).

L'indagine  sulla salute condotta dall'Ontario, *WindVOoice*, aveva riscontrato che 81 dei 98 soggetti intervistati avevano dichiarato di aver subito danni alla salute. Le distanze, ai fini dell'indagine, vanno dai 5 km (2 soggetti) e, per la maggior parte, sono sotto i 1000 m. Questo mette in evidenza la necessità di studi sulla salute multi-disciplinare e indipendenti, inclusi quelli epidemiologici.

Il dr. Buxton consiglia di rivedere i metodi di misurazione e di comprendere sia la ponderazione “C” e “G”  che la solita ponderazione “A”, in modo da ottenere una stima esatta del volume LFN e di infrarosso raggiunto prima, durante e dopo l'installazione della sorgente del rumore.

Circa l'importanza dell'LFN, l'Organizzazione Mondiale della Sanità (OMS), in una pubblicazione del 2000 intitolata “Community Noise” di Berglund et al., ha fatto le seguenti osservazioni:

1) Poichè la ponderazione A sottovaluta il livello di pressione sonora del rumore con componenti di bassa frequenza, per accertare meglio gli effetti sulla salute sarebbe meglio usare la ponderazione “C”.
2) Si dovrebbe considerare il fatto che una grande proporzione di componenti di bassa frequenza in un rumore possono aumentare

notevolmente gli effetti nocivi sulla salute.

3) Le prove sul rumore a bassa frequenza sono sufficientemente valide da giustificare la preoccupazione.
4) Styles et al. avevano osservato che vi sono prove chiave che le turbine eoliche producono un suono a bassa frequenza (infrasuono) e segnali acustici che possono essere rilevati a distanza considerevole (molti km) da rilevatori di infrasuoni e da microfoni per la bassa frequenza.

Nel Luglio del 2008 gli esperti americani Kamperman e James avevano presentato un certo numero di proposte di limitazione del suono per prevenire i rischi sulla salute provocati dalle turbine eoliche. Essi facevano notare che "il fatto che vi siano così tanti abitanti che si lamentano del rumore a bassa frequenza provocato dalle turbine è una prova chiara che una singola misura di rumore con ponderazione A (Dba) utilizzato in molte giurisdizioni per scegliere il luogo di installazione delle turbine è inadeguato". Pertanto, aggiungevano i succitati, "l'unico altro semplice ponderatore di audiofrequenza standardizzato e disponibile per tutti i misuratori di livello di suono è il ponderatore C o dBC". Essi avevano quindi proposto i seguenti limiti per l'installazione di turbine eoliche:

1) Limite sonoro udibile.

A) La turbina o più turbine dovrebbero essere situate in modo da non superare di più di 5dBA i livelli di rumore di fondo misurati prima della costruzione/messa in funzione.

B) I livelli sonori di fondo sono le misure L90A eseguite durante uno studio precostruzione sul rumore e nelle ore più tranquille della sera o della notte. Tutta la registrazione dei dati dovrebbe consistere in una serie di misure continue di dieci (10) minuti. I risultati L90A sono validi quando i risultati L10A non sono superiori di più di 15 dBA a quelli di L90A per lo stesso periodo di tempo. I siti sensibili al rumore devono essere selezionati sulla base delle peggiori previsioni di emissione di suono delle turbine (in LeqA e LeqC) che devono essere fornite dal costruttore.

C) Le posizioni dei test devono essere localizzate lungo il confine della proprietà ricevente ma non partecipante.

D) Una penalità di 5dB è applicata per toni come specificato nella IEC 61400-11.

2) Limitazione del suono a bassa frequenza.

A) I livelli di suono LeqC e L90C che si diffondono dalle turbine all'area ricevente non devono eccedere il livello inferiore di entrambi

i) LeqC ed L90C non superiori a 20db all'esterno di ogni costruzione abitata.

ii) Un livello di suono massimo, da non superare, di 50 dBC (L90C) proveniente dalle turbine senza altri rumori circostanti per le proprietà situate ad un miglio o più dalle Autostrade Statali o dalle altre strade principali; oppure 55 dBC (L90C) a meno di un miglio di distanza.

B) Questi limiti devono essere accertati alla stessa ora notturna e alle stesse condizioni di vento/metereologiche richieste in 1.A. Le emissioni di suoni delle turbine in funzione (LeqA e LeqC) devono rappresentare il peggior caso di emissioni sonore per condizioni notturne stabili con venti deboli al suolo e venti sufficientemente forti  a livello del mozzo per funzionare a pieno ritmo.

3) Clausola generale

A) Non eccedere i 35 dBA entro 30 m (all'incirca 100 piedi) di ogni edificio abitato.

4) Requisiti

A) Tutti gli strumenti devono soddisfare le specifiche di prestazione di ANSI o IEC Precision che integravano il misuratore del livello del suono.

B) Le procedure devono rispettare ANSI S 12,9 ed altri standard applicabili ANSI.

C) Le misure devono essere prese quando i livelli di vento al suolo sono di 2 m/s (4,5 mph) o inferiori. Il gradiente del vento di sera e di notte spesso deriva da una bassa velocità del vento al suolo e dalle velocità nominali operative del vento all'altezza del mozzo della turbina.

D) Le procedure IEC 61400-11 non sono adatte a far rispettare queste esigenze, tranne che per quelle riguardanti la presenza di toni.

INDICAZIONI DEL WHO (Organizzazione Mondiale della Sanità)

La raccomandazione del 2007 dell'OMS indica un limite notturno di 30dBA all'esterno di una abitazione (Lnight esterna)

Le indicazioni del WHO del 2007 enunciano:

"Lnight oltre 30 dB è l'obiettivo finale delle Linee Guida del Rumore Notturno (NNGL) per la protezione del pubblico, inclusi i gruppi più vulnerabili (i bambini, i malati cronici e gli anziani ) dagli effetti nocivi sulla salute causati dal rumore notturno.

P.S. Il rapporto completo può essere scaricato da http://ec.europa.eu/health/ph_projects/2003/action2/docs/2003_08_frep_en.pdf

RUMORE A BASSA FREQUENZA IMPIEGATO COME ARMA

Il prof. Hillel Pratt, un neurobiologo specializzato nella reazione acustica umana presso il Technion Institute in Israele ha affermato: " Il rumore a bassa frequenza non deve necessariamente essere un suono forte. La combinazione di basse frequenze ad alta intensità può, ad esempio, provocare discrepanze negli stimoli al cervello". In seguito, egli ha spiegato che, stimolando l'orecchio interno, che ospita gli organi sensoriali (equilibrio), acustici e vestibolari, con segnali acustici che sono al di sotto delle frequenze udibili (< 20 Hz), l'organo vestibolare può venire stimolato e creare un divario tra gli stimoli provenienti dal sistema visivo ed il sistema somatosensoriale (che registra la stabilità del corpo rispetto all'ambiente) e l'organo vestibolare che registrerà erroneamente un'accelerazione (a causa del suono  inudibile di bassa frequenza). Questo creerà una sensazione simile al mal di mare o mal d'auto. Simili casi sono stati riferiti ed un esempio famoso è quello di persone che lavoravano in un seminterrato con un nuovo impianto di condizionamento: tutte stettero male a causa del rumore a bassa frequenza proveniente dall'impianto.

OSSERVAZIONI SULL'IMPATTO SUL SISTEMA SOCIO-ECONOMICO

In ultimo, ma non per importanza, gli impianti eolici di grande taglia sono causa della perdita del valore delle abitazioni, delle attività agricole e silvo-pastorali. In particolare, dato il numero di abitazioni (u.i.) e di attività agricole che saranno interessate dalla visuale dell'impianto a breve distanza, anche  una perdita di valore dovuta ad una degradazione paesaggistica di impatto limitato (2-5%) può tradursi in una notevole perdita per la collettività.

Ruvo di Puglia, 4/06/2024

# *Sindrome da turbina eolica: una relazione su un esperimento naturale (cioè non artificiale e condotto in laboratorio)*

Nina Pierpont, MD, PhD

## ***Sommario***

20 dicembre 2009

Il contenuto di questo libro è una relazione scientifica su una ricerca originale e pionieristica che riporta e discute i sintomi presentati da individui residenti nelle aree adiacenti a grandi turbine eoliche industriali (1,5–3 MW) erette dal 2004.

I risultati sono stati i seguenti:

1) Le turbine eoliche provocano la sindrome da turbina eolica. Lo sappiamo con certezza a causa della manifestazione dei sintomi negli individui che vivono presso le turbine e della scomparsa dei medesimi, se le persone si allontanano da tali aree. Le stesse famiglie oggetto dello studio hanno compreso di doversi allontanare dalle turbine per liberarsi dai sintomi, e nove su dieci si sono trasferite altrove, vendendo o perfino abbandonando la propria casa.

2) Non si abbandona la propria casa per un "fastidio". I sintomi riportati di insonnia, vertigini e nausea non possono essere valutati come semplici "fastidi".

3) Il cluster di sintomi riscontrati negli individui mostra coerenza e ricorrenza, da qui la denominazione "sindrome".

4) I sintomi in questione sono: disturbo e privazione del sonno, emicrania, tinnito (ronzio nelle orecchie), pressione nelle orecchie, stordimento, vertigini, nausea, visione sfocata, tachicardia, irritabilità, problemi di concentrazione e memoria, attacchi di panico associati a sensazioni di movimento o tremori del corpo durante la veglia o il sonno.

5) Sia i bambini che gli adulti ne sono affetti. In particolare ne risentono gli adulti più anziani.

6) Gli individui con disturbi preesistenti, quali emicrania, sensibilità al movimento o danni alle strutture dell'orecchio interno (come la perdita uditiva provocata dall'esposizione al rumore industriale) mostrano, rispetto agli altri, una maggiore predisposizione alla sindrome da turbina eolica. Questi risultati sono statisticamente significativi ($p < 0{,}01$).

7) I sintomi da sindrome da turbina eolica non sono statisticamente associati all'ansia o ad altri disordini mentali preesistenti.

8) Le dimensioni campione di 10 famiglie (38 persone) sono sufficienti ad ottenere dati statisticamente significativi sulla predisposizione o sui fattori di rischio.

9) I fattori di sensibilità fanno comprendere quale sia la patofisiologia della sindrome da turbina eolica. Il complesso ricorda le sindromi causate da disfunzione vestibolare (organo dell'equilibrio dell'orecchio interno). Si suggerisce che il meccanismo che la provoca sia da attribuire a disturbi del senso di equilibrio e di posizione, causati da rumore e/o vibrazione, ed in particolare dalle componenti a bassa frequenza di rumore e vibrazione.

10) Un'ampia rilettura delle più recenti documentazioni mediche rivela come i segnali neurali collegati all'equilibrio condizionino diverse aree e funzioni del cervello, tra cui la cognizione, la memoria e la risoluzione spaziale dei problemi, la paura, l'ansia, le funzioni autonomiche (come nausea e battito cardiaco) e l'apprendimento avversivo (vedi oltre). Le connessioni con il sistema nervoso rappresentano la base anatomica e psicologica su cui si sviluppa la sindrome da turbina eolica.

11) Nel presente studio è inoltre stata presa in considerazione la documentazione medica e tecnica sulla risonanza del suono o della vibrazione nelle cavità corporee (torace, cranio, occhi, gola, orecchie), data la comparsa di questi effetti nei soggetti studiati.

12) Sono inoltre stati esaminati gli studi pubblicati sull'esposizione documentata al rumore a bassa frequenza (sperimentali e ambientali) che dimostrano sugli individui effetti simili o identici alla sindrome da turbina eolica. Uno studio condotto in Germania nel 1996 potrebbe riguardare la stessa sindrome da turbina eolica.

13) Si sono inoltre presi in considerazione i recenti sondaggi postali, condotti sugli individui residenti nelle aree vicine alle turbine eoliche in Svezia e nei Paesi Bassi, che dimostrano il forte fastidio provocato dalle turbine eoliche con livelli di rumore molto più ridotti rispetto a quelli del traffico, di treni o aeroplani.

14) Si è tenuto conto della documentazione fino ad ora pubblicata sugli effetti del rumore ambientale sulla salute cardiovascolare e sull'apprendimento dei bambini. Per motivi di salute, l'Organizzazione Mondiale della Sanità raccomanda soglie ridotte di rumore notturno che sono oggi osservate in gran parte del mondo, in particolare nel caso di rumore con componenti a bassa frequenza.

15) Con la denominazione "sindrome da turbina" eolica si intende una serie di sintomi sufficientemente seri da far allontanare le persone dalle proprie abitazioni, e si stabiliscono i fattori di rischio per la salute, evidenziati da tali sintomi. Questo studio e altri studi presi in considerazione nella relazione indicano che una distanza sicura deve essere di almeno 2 km e oltre per le turbine più grandi e in una topografia più varia. Un'ulteriore ricerca è necessaria per chiarire le cause fisiche e i meccanismi fisiologici, approfondire alcuni altri effetti sulla salute per coloro che vivono nei pressi di turbine eoliche, determinare il numero delle persone colpite ed indagare gli effetti su determinati gruppi di popolazione, quali i bambini. Il finanziamento e la moratoria dei governi sono indispensabili.

Il libro contiene inoltre:

A) La documentazione completa — le testimonianze e le esperienze di tutti i soggetti inclusi nello studio (compresi i bambini), presentata in formato tabulare.

B) Una relazione presentata in un linguaggio comprensibile e non scientifico, che illustra gli aspetti tecnici e statistici dello studio, e corredata da immagini.

C) Recensioni di colleghi (peer reviews) e commenti di ricercatori scientifici e medici docenti universitari.

D) Introduzione, bibliografia medico-scientifica completa, glossario ed elenco di abbreviazioni.

**NINA PIERPONT, MD, PHD**

# La sindrome da turbina eolica

## Una relazione su un esperimento naturale

Versione ridotta*



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# *La sindrome da turbina eolica: una relazione su un esperimento naturale*

## Versione ridotta per traduzione

Il testo originale in inglese di *La sindrome da turbina eolica*, è un libro in tre parti (comprendente un capitolo introduttivo, un elenco di abbreviazioni, la bibliografia, relazioni di riferimento e altri commenti) che si compongono di:

> **Una Relazione Per Medici**, di taglio scientifico che riporta dati originali e di prima mano, la loro analisi e la discussione della documentazione clinica e scientifica con la bibliografia completa.
>
> **La Documentazione** dei dati delle interviste e le dichiarazioni dei soggetti studiati prima, durante e dopo l'esposizione alle turbine eoliche, in un ordinato formato tabulare.
>
> **Una Relazione Per Non Specialisti**, in cui la ricerca e la discussione vengono ripresentate in un linguaggio semplice e senza matematica. In questa sezione non ci sono note bibliografiche, ma vengono chiariti i concetti basilari, i metodi e le analisi sono trattati più in breve e la discussione sulla letteratura scientifica è ridotta.

La versione ridotta destinata alla traduzione contiene solo **La Relazione Per Non Specialisti**, le relazioni di riferimento e altri commenti. Alcuni brevi estratti del capitolo introduttivo e della **Relazione Per Medici** sono integrati nella versione ridotta, ma sono privi di bibliografia.

La traduzione della versione ridotta non è dunque sufficiente per studiosi, medici, e avvocati, ma funge esclusivamente da introduzione alla relazione e alla bibliografia originali in lingua inglese.

**La Relazione Per Non Specialisti** Ho scritto la relazione per "non addetti ai lavori" per rendere la ricerca più accessibile a chiunque, dalle persone affette da sindrome da turbina eolica ai funzionari locali coinvolti nei dibattiti sulle autorizzazioni. Questo è lo scopo previsto anche per le traduzioni in lingue straniere.

## COMMENTI E RECENSIONI

"Straordinario, interessante e importante."

> —ROBERT M. MAY, PhD, Professor Lord May of Oxford OM AC Kt FRS. Presidente della Royal Society (2000–05), Capo dei consiglieri scientifici del governo britannico (1995–2000). Lord May è uno dei maggiori esponenti della ricerca sul riscaldamento globale ed è considerato un pioniere della ricerca epidemiologica.

"La Dott.ssa Pierpont ha definito clinicamente un nuovo gruppo di individui che reagisce a basse frequenze, cioè a forze di ampiezze relativamente elevate che condizionano il sistema sensorio ed altri sistemi dell'organismo. Le sue rigorose osservazioni cliniche sono compatibili con le relazioni sugli effetti deleteri dell'infrasuono sugli esseri umani, e comprendono (ma non sono limitati a questi) anche gli effetti sonar a bassa frequenza sui sommozzatori. Ci sono particolari patologie (come ad esempio le rotture dei canali semicircolari superiori) che potrebbero spiegare parte della relazione sui sintomi clinici della Dott.ssa Pierpont, tuttavia questa condizioni sono relativamente rare e non possono spiegare tutti i casi da lei osservati".

"La perspicace raccolta di osservazioni della Dott.ssa dovrebbe dare inizio a una ricerca d'indagine controllata, basata su più siti e condotta da più istituzioni."

> —F. OWEN BLACK, MD, FACS, Primo ricercatore e Direttore della ricerca neuro-otologica presso Legacy Health System, Portland, Oregon. Il Dott. Black è considerato uno dei maggiori ricercatori e uno degli specialisti più all'avanguardia degli Stati Uniti, nel campo della ricerca sull'equilibrio e sull'orientamento.

"Come è successo a numerosi pionieri della medicina che hanno esposto le debolezze dell'ortodossia contemporanea, la Dott.ssa è stata oggetto di denigrazione e critiche. La pubblicazione di questo importante documento è un tributo alla sua forza di carattere e alla sua convinzione. Il resoconto dettagliato dei danni causati dal rumore delle turbine eoliche offre un robusto fondamento per la ricerca futura. Una lettura obbligatoria per tutti i progettisti che lavorano agli impianti eolici."

> —CHRISTOPHER HANNING, MD, FRCA, MRCS, LRCP. Il Dott. Hanning, è il fondatore della British Sleep Society, uno dei maggiori specialisti e ricercatori nel campo del sonno. Ha di recente lasciato il suo incarico di Direttore della Sleep Clinic and Laboratory presso il Leicester General Hospital, uno dei più grandi centri britannici per lo studio dei disturbi del sonno, per raggiunti limiti di età.

"Questo libro è eccezionale. Personale ed appassionato, è una lettura coinvolgente, ma è molto di più: è anche autorevole, meticoloso e scientifico. Le descrizioni anatomiche, fisiologiche e patofisiologiche di come il rumore condiziona la salute vengono colte con precisione. Questo libro rappresenta l'opera più significativa nel campo di questa ricerca.

“Oltre ai dettagliati resoconti clinici della Dott.ssa Pierpont, si moltiplicano le dimostrazioni di effetti negativi sulla salute in Giappone, Nuova Zelanda, Regno Unito, Stati Uniti e Canada. Esistono all’incirca 357 organizzazioni in 19 diversi paesi europei che sollecitano un’inchiesta dell’Unione Europea sulla salute e sui molti altri effetti negativi prodotti dagli impianti eolici. Come minimo L’Unione Europea dovrebbe dimostrare saggezza e consultare la Dott.ssa Pierpont.

“Tutti i professionisti nel campo della medicina, e in particolare quelli coinvolti nella pratica clinica, dovrebbero leggere questo libro. Si deve solo sperare che i politici e gli strateghi politici ad ogni livello prendano coscienza delle serie conseguenze derivanti da decisioni frettolose nell’ambito della cosiddetta energia pulita”.

> —ROBERT Y. McMURTRY, MD, FRCS (C), FACS. Ex Decano presso la facoltà di Medicina e Odontoiatria presso la Schulich School of Medicine & Dentistry, University of Western Ontario. Il Dott. McMurtry vanta una lunga e distinta carriera nella politica sanitaria canadese a livello federale e provinciale, è inoltre Viceministro aggiunto e fondatore della Population and Public Health Branch of Health Canada e attualmente è membro dell’Health Council of Canada.

“La Dott.ssa Pierpont ha creato un libro eccezionale e autorevole. Eccellente nella presentazione di dati concreti e nella considerevole chiarezza.

“Mi auguro davvero che i risultati raggiunti, presentati come inconfutabile ricerca sottoposta alle recensione di rinomati colleghi, giunga all’attenzione di persone influenti in grado di ampliare la base di ricerca e di influenzare la politica di gestione della sindrome da turbina eolica”.

> —JACK G. GOELLNER, Direttore emerito, The Johns Hopkins University Press (la casa editrice universitaria più antica degli Stati Uniti, fondata nel 1878). Nel corso della sua carriera di direttore presso la JHUP, Goellner è divenuto famoso a livello internazionale, noto, tra l’altro, per le sue pubblicazioni mediche.

“La Dott.ssa Pierpont ha dato un importante contributo al dibattito sulle turbine eoliche, che non dovrebbe essere solamente condotto tra sostenitori e oppositori dell’energia rinnovabile, ma piuttosto dalla comunità di coloro che desiderano un paese responsabile al livello ambientale. Lo possiamo e lo dobbiamo fare”.

> —COMITATO EDITORIALE DI *THE INDEPENDENT* (GB), agosto 2, 2009

# La relazione in un linguaggio semplice per non specialisti

## Compendio e contesto

Ho intervistato 10 famiglie residenti nelle aree adiacenti a grandi turbine eoliche (1,5–3MW), tutte erette dal 2004, per un totale di 38 individui, inclusi neonati e 75enni. I sintomi mostrati hanno fornito un cluster (sono cioè diffusi e ricorrenti in tutto il gruppo di individui studiati).

1) Sonno disturbato
2) Emicrania
3) Tinnito (ronzio nelle orecchie)
4) Pressione delle orecchie
5) Vertigini (nel senso generico, inclusi stordimento e sensazione di quasi svenimento, ecc.)
6) Vertigini (nel senso clinico, cioè sensazione di rotazione o movimento della stanza)
7) Nausea
8) Visione sfocata
9) Tachicardia (battito cardiaco accelerato)
10) Irritabilità
11) Problemi di concentrazione e memoria
12) Attacchi di panico associati a sensazione di pulsazione e tremori interni, durante la veglia o il sonno.

I membri di queste famiglie hanno notato la comparsa dei sintomi in seguito all'attivazione delle turbine nei pressi delle loro abitazioni e ne hanno constatato la scomparsa ogni qualvolta si allontanavano. Al ritorno a casa, i sintomi si manifestavano di nuovo. Otto delle 10 famiglie si sono alla fine spostate altrove, perché troppo disturbate dai sintomi e, in alcuni casi, hanno abbandonato le proprie abitazioni.

La conclusione finale della mia ricerca è dunque che le turbine eoliche provocano la sindrome da turbina eolica. Lo dimostro nel modo appena descritto, dettato dal buon senso.

Chiariamo subito un punto. Non tutti coloro che abitano nelle vicinanze delle turbine eoliche presentano questi sintomi. Essendo una ricercatrice singola e senza finanziamenti, non ho potuto raccogliere il numero di campioni necessario per calcolare statisticamente quali percentuali di persone e a quali distanze accusano questi sintomi. Questo sarà un argomento da affrontare in seguito. Tuttavia sono riuscita a prendere in considerazione la questione del perché alcune persone sono sensibili ed altre no, e a indagare su chi è sensibile. Ho usato questi dati per indagare la *patofisiologia della sindrome da turbina eolica* (cosa accade all'interno dell'organismo per provocare questi sintomi specifici).

Vorrei che i lettori esaminassero questo studio, le dettagliate testimonianze da me raccolte dagli individui residenti vicino a turbine e la loro anamnesi, in modo da essere in grado di valutare se queste persone possano essere esposte alle turbine.[1]

Ho provato che, senza dubbio, gli individui affetti da emicranie, sensibilità al movimento (quali mal d'auto o mal di mare) o danni dell'orecchio interno preesistenti sono particolarmente vulnerabili a questi sintomi.

Egualmente importante è la dimostrazione che individui affetti da ansia o da altri preesistenti problemi mentali sono scarsamente predisposti.

Tutto ciò contraddice la documentazione dell'industria eolica che attribuisce la comparsa dei sintomi in persone ansiose o che, in qualche modo, sono contrari ad avere turbine nei pressi della loro abitazione. Dimostrerò che è una vera assurdità.

Questo è quel che succede, da quanto si deduce dagli indizi da me raccolti. *Il rumore o la vibrazione a bassa frequenza ingannano il sistema di equilibrio del corpo e lo inducono a pensare che si stia muovendo*. Come capita con il mal di mare. È fondamentale comprendere il sistema dell'equilibrio umano come un sistema complesso, con il cervello come organo centrale che riceve segnali nervosi da orecchi interni, occhi, muscoli, articolazioni e all'interno del torace e dell'addome. Poiché sono coinvolti gli occhi, anche il disturbo visivo del passaggio dell'ombra delle pale peggiora il disturbo dell'equilibrio.

Ripeto questo concetto, perché è di fondamentale importanza. *Il rumore o la vibrazione a bassa frequenza ingannano il sistema di equilibrio del corpo e gli fanno credere che si stia muovendo.* Che ne dite? Non troppo in fretta! La ricerca degli ultimi 10 anni dimostra in modo inconfutabile che *il modo in cui il corpo registra l'equilibrio e il movimento, influenza direttamente una serie di funzioni cerebrali.*

Come? Attraverso dei legami neurologici diretti che collegano gli organi dell'equilibrio a diverse funzioni del cervello, solo apparentemente separate.

Desidero ripetere questo concetto in altre parole, perché è fondamentale per la discussione all'interno di questa relazione. *Il modo in cui il corpo percepisce l'equilibrio e il movimento influenza a sua volta una moltitudine di funzioni cerebrali, che all'apparenza potrebbero sembrare completamente distinte.* Come già menzionato, questi sono i risultati della ricerca più recente "sull'equilibrio", in particolare della ricerca sull'equilibrio, associata alla ricerca psichiatrica, neurologica e cognitiva.

Incidentalmente, gli esperti in questo tipo di ricerca sono denominati *otoneurologi* (Europa) e *neurotologi* (Stati Uniti), dalla radice *oto,* cioè orecchio, e *neuro,* cioè cervello.

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1. Vedere Nina Pierpont, La sindrome da turbina eolica: una relazione su un esperimento naturale (Santa Fe, NM: K-Selected Books, 2009), 294 pp., per la relazione integrale (in lingua inglese).

Quali sono le funzioni cerebrali apparentemente distinte che vengono condizionate dalla nostra percezione di equilibrio e movimento?

1) *Movimenti muscolari automatici o di riflesso.* Sono i noti riflessi vestibolo-oculari, che compensano automaticamente i movimenti degli occhi con i movimenti della testa e i riflessi vestibolo-collici e vestibolo-spinali, che regolano dinamicamente il tono muscolare del collo e del dorso per mantenere la postura durante il movimento.

2) *Stato di vigilanza,* vale a dire attenzione, allerta e risveglio.

3) *Processo spaziale e memoria.* Il processo spaziale comporta il ragionamento basato sulle immagini o sugli schemi che utilizziamo costantemente per:

   a) immaginare le cose

   b) ricordare dove sono le cose e dove sono situate

   c) ricordare come raggiungere un luogo

   d) comprendere il funzionamento delle cose

   e) immaginare il risultato che vogliamo ottenere

   f) decidere come assemblare o riparare qualcosa

   g) determinare quale siano l'ordine e i tempi più efficienti per eseguire qualcosa (ad esempio come lavorare in cucina, in fattoria, in barca da pesca o sbrigare una serie di commissioni)

   h) ricordare l'obiettivo quando si giunge in un luogo (ad esempio commissioni da fare in città)

   i) comprendere concetti matematici, e

   j) molti altri tipi di ragionamento critico.

4) *Manifestazioni fisiologiche di paura*, vale a dire palpitazioni cardiache, elevata pressione sanguigna, sudorazione, nausea, tremori e iper-vigilanza.

5) *Apprendimento avversivo.* Si tratta di un tipo di apprendimento riflesso la cui funzione è garantire che persone e animali evitino delle cose potenzialmente dannose. Un esempio classico sia per umani che per animali è il vomito dopo aver ingerito un certo tipo di cibo. In seguito, si tende ad evitare quel particolare cibo per lungo tempo, anche se non è stato la causa del vomito e se è accaduto una sola volta (ricordate questa esperienza da bambini?). Questo tipo di apprendimento è talmente incisivo e automatico che anche l'ambiente associato a questa esperienza può innescare una sensazione di nausea, come ad esempio l'odore o la vista di un particolare cibo o persino avvicinarsi allo stesso ristorante. Si tratta di un antico

riflesso evolutivo, destinato ad impedire a mammiferi e uccelli l'ingestione di sostanze tossiche (con risvolti particolarmente interessanti nell’evoluzione della farfalla, ma quella è un’altra storia). L’aspetto importante è la programmazione biologica che ci porta ad evitare le cose che ci nauseano.

Bene. *Contrazioni muscolari degli occhi, collo e colonna vertebrale, lo stato di allerta/ veglia, il processo spaziale e la memoria, le manifestazioni fisiologiche della paura e dell’apprendimento avversivo*. Queste cinque funzioni cerebrali sono profondamente condizionate dalla sensazione di equilibrio e movimento. Tutte e cinque sono perturbate se il senso dell’equilibrio è compromesso.

Torniamo alle turbine eoliche. Consultando online un qualsiasi articolo di giornale sulla sindrome da turbina eolica si noterà quasi invariabilmente che alcuni dei commenti ridicolizzano l’intero concetto per l’ovvia ragione che è impossibile immaginare un collegamento tra una così ampia gamma di problemi di salute (memoria insufficiente, elaborazione spaziale, ansia, paura, panico e apprendimento avversivo) e le turbine eoliche. “Assurdo! Naturalmente - continua l’intelligente blogger - la manifestazione di questi sintomi è il frutto dell’immaginazione delle persone che vivono presso le turbine (probabilmente perché non amano quelle insopportabili macchine) ed il medico che prende seriamente questi disturbi (in questo caso io) è un profittatore e un imbroglione”.

A questo rispondo: chiaramente gli autori di queste perle di logica non sono né neurobiologi né medici e non sono nemmeno affetti dai sintomi che inequivocabilmente numerosi individui riportano all’ombra (per così dire) delle turbine eoliche industriali.

Torniamo alla medicina vera e propria. I sintomi di cui sopra si verificano *perché gli esseri umani sono programmati biologicamente per mostrare questa precisa costellazione di sintomi quando i loro sensori di equilibrio e movimento vengono disturbati*, come accade a numerosi individui residenti nelle vicinanze di turbine eoliche.

È importante sottolineare che questi sintomi non sono psicologici (cioè frutto dell’immaginazione), ma neurologici. Coloro che ne vengono colpiti non sono in grado di controllare la propria reazione alle turbine, essa avviene automaticamente. Non si possono innescare o bloccare questi sintomi.

Dobbiamo sottolineare il fatto che i *segnali di equilibrio sono l’unico tipo di segnali sensori che non possono essere ignorati*. Si può ignorare ciò che si vede e si sente, ma non quello che proviene dal senso di equilibrio. Potete anche chiamare questo fatto una “legge di natura”.

Che cosa ci fornisce il senso dell’equilibrio? Bella domanda. L’equilibrio ha origine da una combinazione di segnali. Vorrei riformulare il concetto: l’equilibrio ha origine *da un gruppo di segnali provenienti da diversi organi del corpo*, tra cui l’orecchio interno.

Stop! Qui dobbiamo illustrare l’anatomia dell’orecchio interno, poiché è fondamentale per comprendere la sindrome da turbina eolica.

Iniziamo con lo strano lembo di pelle al lato della testa, che serve a sostenere gli occhiali e gli orecchini. Non si tratta dell’orecchio esterno, ma della pinna (i pugili acquisiscono una pinna a cavolfiore). L’orecchio esterno è il punto in cui si inseriscono i cotton fioc e dove un bambino di due anni infila le perline e altri tesori. È dove c’è il cerume e dove l’acqua resta imprigionata dopo la doccia ed è necessario farla uscire. L'orecchio esterno è una tasca cieca che termina con il timpano che sigilla la tasca all'estremità interna.

Poi arriva l'orecchio medio, tra il timpano e la finestra ovale, il punto in cui si verificano le infezioni dei bambini piccoli (mamme, ricordate tutte le volte che vi siete recate dal medico con Johnny e vi è stato detto: "Sì, Johnny ha un 'infezione dell'orecchio". Tutto questo dopo che Johnny si era svegliato strillando in piena notte e in seguito a tre giorni di raffreddore). L'orecchio medio è aperto all'aria attraverso la tuba d'Eustachio dal retro della gola (dietro il naso).

L'orecchio medio racchiude tre eccezionali ossicini: incudine, martello e staffa, che sono concatenati. L'incudine, il martello e la staffa trasmettono l'energia del timpano vibrante all'orecchio interno.

Qui arriviamo al punto. L'orecchio interno (o labirinto membranoso) comprende la coclea, i canali semicircolari (che ricorderete dalle lezioni di biologia della scuola superiore) e i cosiddetti organi otolitici (che sicuramente non ricorderete dalle lezioni di biologia).

Gli organi otolitici sono essenziali per capire la sindrome da turbina eolica e comprendono due piccole sacche membranose, l'utricolo e il sacculo, che sono attaccate alla coclea (l'organo membranoso a spirale che traduce l'energia meccanica sonora in segnali nervosi) e ai canali semicircolari (organi membranosi che creano un semicerchio in ognuno dei tre piani di movimento: avanti in verticale, di lato in verticale e orizzontale, trasmettendo l'accelerazione angolare: quando la vostra testa annuisce o si gira, se ne accorgono).

Inclusi nei due organi otolitici ci sono, credetelo o no, dei sassi (*oto* = orecchio e *lita* = sasso. Ricordate l'insegnante quando diceva che avevate la testa piena di sassi?). Certo, non proprio dei sassi, ma dei cristalli microscopici di carbonato di calcio (come calcite o guscio di ostrica) denominati otoconia, aggregati in massa su un gruppo di cellule ciliate (macula) che rilevano il movimento. Il peso e la massa di questi sassolini permettono alle cellule ciliate di percepire la gravità e l'accelerazione lineare.

Ora viene veramente il bello. Immaginate Dio "con queste grandi mani da scultore mentre sfoglia le pagine del libro scuro degli inizi", mostrandoci il modello dei canali semicircolari e degli organi otolitici.[2] Le strutture sono fondamentali per il funzionamento del cervello e vengono condivise da pesci, anfibi e dai (cosiddetti) vertebrati superiori. Sì le abbiamo anche noi. In ognuna di queste creature questi organi assolvono una funzione, non solo più antica di quanto la mente possa comprendere, ma anche talmente profonda che è arrivata a definire cosa sia la mente stessa (nota: nei mammiferi la coclea, l'organo utilizzato per l'udito, si è evoluta molto più tardi).

Siamo alla presenza della principiale chiave della mente dei mammiferi (non solo dei mammiferi, ma dell'intero mondo dei vertebrati). Ebbene, cari lettori, è proprio la chiave principale che viene ingannata dal rumore a bassa frequenza dell'imponente turbina eolica che gira fuori della vostra finestra.

2. Rilke, Rainer Maria. 1991. "The Angels," trans. Snow. *The Book of Images: A Bilingual Edition*, rev. ed. North Point Press, New York, p. 31.

Ci troviamo alla presenza di strutture anatomiche davvero antiche, di molti milioni di anni. Pesci, anfibi e vertebrati “superiori” possiedono tutti canali semicircolari e organi otolitici.

Considerate questo aspetto. Il pesce teleosteo, come il merluzzo, ascolta attraverso i propri organi otolitici, che sono dei rilevatori del suono e della vibrazione, il movimento dei predatori o delle prede vicine. Gli organi otolitici percepiscono anche la forza di gravità (da che parte arriva) e l’accelerazione (se il pesce si muove o si gira). Gli organi otolitici del merluzzo atlantico sono così sensibili alle perturbazioni dell’acqua causate da infrasuono (a 0,1 Hz o un’onda ogni 10 secondi) da renderlo capace di utilizzare i suoni sismici provenienti dalla Dorsale medio-atlantica o il suono delle onde che si frangono su coste lontane, a centinaia di miglia di distanza, per guidarlo durante la migrazione.

Considerate inoltre questo. Nelle rane, il sacculo (uno degli organi otolitici) è la parte dell’orecchio più sensibile alle vibrazioni trasmesse dal substrato. Entrambi, il sacculo e la papilla basilare (la parte dell’orecchio della rana evolutasi più tardi), percepiscono il suono e la vibrazione con il sacculo che è capace di catturare le frequenze più basse, e con la papilla che percepisce quelle più alte.

L’idea che i nostri organi otolitici erano in origine rilevatori di suono, vibrazione e suono a bassa frequenza, e in più percepivano la gravità e il movimento del corpo, è importante come base su cui lavorare. Gli organi otolitici umani hanno conservato alcune di queste funzioni: reagiscono infatti al rumore o alla vibrazione mediante l’invio di segnali vestibolari.

Se stimolati da uno scatto rumoroso o da un suono improvviso, gli organi vestibolari umani normali innescano un riflesso specifico e misurabile: un segnale elettrico ai muscoli frontali del collo (denominato “potenziale miogenico evocato vestibolarmente” o VEMP). Fatemi ripetere questo concetto con altre parole, perché è importante: un rumore, che raggiunge l’orecchio senza alcun movimento della testa o del corpo, innesca una catena di eventi rapida (neurale) che cambia il tono muscolare del collo. Il segnale del muscolo del collo fa parte del riflesso vestibolo-collico. Lo scopo del riflesso vestibolo-collico è stabilizzare la testa durante il movimento del corpo e della testa. *Un rumore, anche se si tratta di un rumore forte e caratteristico, innesca una catena di riflessi di eventi e dimostra che il sistema vestibolare pensa che la testa e il corpo si stiano muovendo, anche se in realtà non lo fanno. Ebbene sì, ciò succede in esseri umani normali, sani e adulti* (costruttori di impianti eolici mi state leggendo?)

Il rumore però non non arriva solamente attraverso l’aria, il timpano e l’orecchio medio. Le vibrazioni o il suono, trasmessi attraverso le ossa, raggiungono l’orecchio interno direttamente attraverso l’osso che struttura l’orecchio interno. Per simulare questa condizione negli esperimenti o durante un esame clinico, un oggetto vibrante viene appoggiato sulla pelle sopra l’osso mastoideo dietro l’orecchio. Quando un segnale è trasmesso attraverso le ossa è necessaria meno energia (livello di decibel ridotto) per innescare la risposta vestibolare che non quando il segnale arriva all’orecchio medio attraversando l'aria. Inoltre la conduzione attraverso le ossa funziona meglio a frequenze di suono o vibrazioni più basse.

Sensazionale! N*el 2008 è stato dimostrato che il normale sistema vestibolare umano ha una sensibilità simile a quella dei pesci e delle rane a vibrazioni di bassa frequenza.*
Nell’esperimento, un’asta vibrante è stata appoggiata sulla pelle, sopra l’osso mastoide, utilizzando una forza attentamente calibrata. I soggetti sono stati in grado di percepire le vibrazioni come suoni e i ricercatori hanno rilevato la risposta vestibolare misurando i segnali

elettrici provenienti dai muscoli oculari dei soggetti. È interessante notare che questa risposta mostra un distinto picco di sintonizzazione a 100 Hz, e dimostra che c'è una maggiore risposta muscolare oculare vestibolare a 100 Hz che a frequenze maggiori o minori (per confronto, 100 Hz equivale a Sol-Sol#, un'ottava e mezza più bassa di Do medio, cioè i tasti 23–24 del pianoforte). *Con questa nota la vibrazione produce ancora un responso vestibolare misurabile (segnali elettrici del muscolo oculare) anche quando l'intensità della vibrazione era talmente ridotta che i soggetti non potevano percepire più i suoni. In effetti, la potenza della vibrazione che ha prodotto una risposta vestibolare era solo il 3% della potenza che i soggetti erano in grado di udire (15 dB più bassi).*

Ciò significa che alcune parti degli organi vestibolari dell'orecchio interno sono più sensibili alle vibrazioni o al suono di quanto non lo sia la coclea. Gli autori di questo studio ritengono che sia l'utricolo, uno dei due organi otolitici, alcune speciali cellule ciliate, sensibili alla vibrazione, e le fibre nervose che si si trovano tra altre cellule ciliate nell'utricolo e in altri organi vestibolari.

Il fatto è sorprendente (e sarebbe stato un'eresia se non fosse stato dimostrato con un esperimento ben congegnato) . Negli ultimi 70 anni infatti è stato considerato un principio del vangelo che se una persona non riesce a sentire un suono, questo è troppo debole per essere percepito o registrato da qualsiasi altra parte del corpo. Ora possiamo eliminare questo principio, perché è risultato sbagliato. (ciò significa che anche l'uso di misurazioni di pesatura A negli studi del rumore ambientale è superato).

> E scenda il silenzio,
> che attraverso i canali dell'orecchio,
> possa scorrere come un fiume
> il suono ondeggiante del mare.
>
> —da W. H. Auden, "Look, Stranger"

Torniamo a parlare di che cosa genera il senso dell'equilibrio. Ho detto che l'equilibrio deriva da una combinazione di segnali e ho appena spiegato in quale modo alcuni di essi hanno origine nell'orecchio interno. Oltre all'orecchio interno, anche gli occhi inviano al cervello segnali di movimento e di posizione. I muscoli e le articolazioni di tutto il corpo si comportano in modo simile, coinvolgendo i cosiddetti recettori "di stiramento", che comunicano dove ci troviamo nello spazio.

Infine, il corpo mantiene l'equilibrio mediante i (recentemente scoperti) recettori di pressione e di stiramento nel torace e nell'addome. Questi piccoli recettori si avvalgono di vari organi, tra cui i vasi sanguigni e il sangue in essi contenuto, e li usano come pesi o masse per percepire l'orientamento del corpo in presenza della forza di gravità e in altre forme di accelerazione.

Queste informazioni forniscono il contesto ideale per lo studio dei disturbi causati dalle turbine eoliche. Generalmente l'industria eolica considera assurdi questi disturbi (come l'industria del tabacco che ha negato i problemi di salute legati al fumo). Coloro che lavorano nell'industria eolica tuttavia non sono né medici, né persone che soffrono della sindrome da turbine eoliche.

Spero che la ricerca scientifica sia presto in grado di rilevare e collegare ai sintomi, in tempo reale, il rumore e la vibrazione subudibile e udibile delle turbine eoliche che si manifestano negli individui, vale a dire durante il manifestarsi dei sintomi (ciò è stato fatto per simili disturbi in casi già pubblicati, come si vedrà in seguito).

Per il momento, metto intanto a disposizione la mia relazione come studio pilota.

È importante capire che la sindrome da turbina eolica non corrisponde alla malattia vibro-acustica. Desidero ribadire questo concetto poiché spesso nei media questi disturbi sono confusi e considerati come uno solo. I meccanismi sono differenti e le ampiezze del rumore sono indubbiamente diverse.

Come spiegazione, si propone che la sindrome da turbina eolica sia un fenomeno sensorio e neurologico mediato dal sistema vestibolare, come si è definito in precedenza. Si ipotizza invece che la malattia vibro-acustica venga causata da danni ad una varietà di organi che creano un ispessimento delle strutture di supporto ed altre alterazioni patologiche. L’agente sospetto è il rumore a bassa frequenza ad alta ampiezza (alta potenza o intensità). Il mio studio non è per ora (vedi protocollo di studio) in grado di dimostrare se l’esposizione alle turbine eoliche provochi i tipi di patologie presenti nella malattia vibro-acustica. Vi sono tuttavia somiglianze che potrebbero essere oggetto di un’ulteriore indagine medica, in particolare in relazione all’asma e alle infezioni delle vie respiratorie inferiori.

Passando a un altro argomento, mi è stato chiesto se la sindrome da turbina eolica potesse derivare da campi magnetici o elettrici. Non ho alcun motivo di pensarlo. Fin dal 1979 sono state condotte numerose ricerche epidemiologiche sui campi magnetici e sulla salute, confrontando persone non esposte con persone che risiedevano vicino a cavi ad alta tensione o che lavoravano negli impianti elettrici o in altre industrie in cui il campo magnetico era probabilmente elevato. Il complesso di dati ottenuti con questa ricerca non ha dimostrato che l’esposizione ai campi magnetici possa provocare il cancro nei bambini o negli adulti, patologie cardiache o psichiatriche, demenza o sclerosi multipla. Dopo trent’anni di ricerca, non esiste ancora alcuna prova sperimentale accertata di meccanismi fisiologici sugli effetti dei campi magnetici fino ad ora ipotizzati.

Ciò rende difficile eseguire studi epidemiologici, poiché i ricercatori non sanno quale esposizione sia da prendere in considerazione nello studio o che periodo di esposizione possa essere significativo (ad es. la scorsa settimana o cinque anni fa). È stato dimostrato che esiste una connessione tra l’esposizione al campo magnetico dei lavoratori generici e la sclerosi laterale amiotrofica (SLA), una patologia neurodegenerativa, dovuta molto probabilmente alla elevata frequenza di scariche elettriche in questi ambienti e non ai campi magnetici. Le affermazioni che le irregolarità di potenza e di frequenza nelle correnti alternative usate nelle abitazioni (la cosiddetta “elettricità sporca”) creino un’ampia serie non specifica di problemi medici, dall’ADHD ad eruzioni cutanee, diabete e cancro, non sono affatto fondate e non presentano alcun meccanismo biologico plausibile.

## Introduzione allo studio pilota e nozioni di base

Chi produce turbine afferma che sono silenziose, non più rumorose di un frigorifero di casa. Con questa affermazione, ovviamente falsa, riescono a convincere facilmente le amministrazioni locali che erigere turbine a meno di 100 m di distanza dalle abitazioni e, in molti casi, quasi nel cortile di casa, non è un problema.

In altre parole,  i problemi causati dalle turbine, sono provocati dall'industria che le produce. Praticamente non esistono norme governative.

È questo è il momento in cui il mio telefono comincia a squillare (e arrivano e-mail). Persone che mi contattano da tutto il mondo per dirmi, spesso con voce rotta dall'emozione, di non aver dormito bene (se non affatto) da quando le turbine erano state erette a circa 460 metri (e oltre) dalla porta posteriore della propria abitazione. Non si tratta di sola insonnia, ma, nuovamente, di un'intera serie di problemi di salute, sorti da quando le turbine sono state attivate nel campo vicino.

Ho ascoltato per oltre 4 anni, le lamentele di persone che descrivevano sintomi, notevolmente simili da una persona all'altra. Sintomi simili e, spesso, debilitanti che, come presto ho iniziato a rendermi conto, sembrano indicare che il sistema di equilibrio delle persone venisse disturbato.

Ho capito che era necessario definire su basi cliniche il modo in cui le persone si ammalano vivendo vicino alle turbine. Ho pensato che se i sintomi dovessero formare un cluster coerente, saremmo in una posizione migliore per comprendere:

a) la causa precisa

b) il numero di persone colpite

c) gli individui predisposti

d) i metodi di controllo e prevenzione

Questo è divenuto il mio obiettivo: comprendere la patofisiologia del cluster patologico descritto da tutti.

È tuttavia immediatamente sorto un problema. I produttori si concentrano sul rumore, e assoldano un esperto di acustica per far misurare i livelli di rumore (tra l'altro, ci sono diversi metodi di elaborazione dei dati di misurazione). L'esperto poi scrive una relazione che dice:

a) le turbine emettono tot dB di rumore

b) da quanto è convenzionalmente noto sull'acustica, si sostiene che questa gamma di dB non crea problemi

c) di conseguenza si conclude che queste persone stanno simulando i sintomi

d) questione chiusa

Rovesciamo il concetto: dobbiamo iniziare con c) *sintomi* e non con a) *livello di rumore*. I sintomi sono simili e ricorrenti tra tutte le persone colpite, in Inghilterra, in Canada o altrove. Inoltre, il cluster sintomatologico rispecchia i meccanismi clinici conosciuti. Nessun mistero.

Da questo si deduce che il cluster di sintomi diviene (e deve necessariamente divenire) il punto di riferimento principale.

Nella misurazione del rumore è necessario raccogliere dati più dettagliati in modo da essere in grado di definire le esatte qualità dello spettro del rumore, *nel momento esatto in cui appaiono i sintomi e, al contrario, quando i sintomi scompaiono*. A questo servono le misurazioni del rumore.

A proposito, anche altre relazioni pubblicate sulla salute e sulle turbine eoliche, identificano la stessa identica serie di sintomi da me riportati. Nella mia relazione integrale ho preso in considerazione i documenti dei Dott. Amanda Harry, Barbara Frey, Peter Hadden e del Prof. Robyn Phipps.[3]

1) Harry ha riscontrato gli stessi problemi. Limitandosi ad osservare gli individui colpiti dai sintomi, ha visto che si otteneva un gruppo di individui più anziani. Ciò suggerisce che l'avanzamento dell'età è un fattore di rischio.

2) Frey e Hadden hanno documentato gli stessi sintomi nei resoconti delle singole persone.

3) Phipps ha inviato un questionario a tutti coloro che risiedevano a circa 15 km dalle turbine. Tutti coloro che hanno risposto vivevano a circa 2 km dalle turbine. Ha avuto risposte positive riguardanti sintomi spiacevoli dal 2% dei partecipanti. Ha ricevuto telefonate dal 7% delle persone che la chiamavano di loro iniziativa per illustrare in modo più dettagliato i loro disturbi ed i problemi. La maggior parte di queste persone manifestava disturbi del sonno. Sì, perfino alla distanza di 2 km!

Le persone da me intervistate hanno spiegato che i loro problemi sono causati dal rumore e dalle vibrazioni e, in qualche caso, dall'ombra rotante delle pale. Hanno inoltre notato che i sintomi andavano e venivano a seconda della direzione e della forza del vento, della velocità, di rotazione delle pale, della posizione delle turbine e dei suoni che emettevano.

In altre parole, I loro sintomi aumentavano o diminuivano a seconda di quello che facevano le turbine. Hanno riportato anche che la qualità del rumore è strana e fastidiosa, rispetto ad altri tipi di rumore, come ad esempio treni o traffico nelle vicinanze. Alcuni di loro erano particolarmente disturbati dal movimento delle ombre nelle stanze o dall'ombra delle pale che percorreva il paesaggio.

Ma soprattutto, i sintomi scomparivano quando i soggetti si allontanavo dall'abitazione e dalle turbine e ricomparivano poi al ritorno a casa. Alla fine, la maggior parte dei soggetti dello studio hanno definitivamente abbandonato le loro case.

Ripeto, l'unico modo efficiente per studiare il problema è considerare *prima i sintomi e poi la misurazione dei livelli di rumore* e non il contrario.

Il rumore. Cari lettori, prima di procedere oltre bisogna comprendere che cosa sia il rumore. Se pensate di saperne a sufficienza saltate i prossimi paragrafi, altrimenti ecco qua:

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3. Pierpont (2009).

Le turbine eoliche emettono un rumore infrasonico (sotto il livello che possiamo sentire), passando da una gamma di rumori udibili a ultrasuoni (rumori che non possiamo sentire). Questo è un dato di fatto. Per “infra” e “ultra” si intende “tono”. “Frequenza” significa “tono”. Per cui, il rumore a bassa frequenza significa “a basso tono” come le note basse di un pianoforte. L’alta frequenza corrisponde ad un tono alto, come il suono “s” del linguaggio umano. La frequenza viene misurata in Hertz (Hz), cioè in “onde o cicli al secondo”.

Il rumore possiede anche una proprietà di intensità o potenza, che nel caso del livello di udibilità, viene definita “intensità”. L’intensità viene misurata in “decibel” o “livello di pressione sonora”. Entrambe queste misure indicano la quantità di energia o potenza dell’onda sonora, denominata anche “ampiezza”.

La prossima definizione è la “lunghezza” d’onda. Un’onda ad alta frequenza indica un’onda corta (immaginate le onde dell’oceano: quando giungono alla riva in rapida successione, la distanza tra i picchi è breve). Una bassa frequenza significa invece un’onda lunga: i picchi tra di essi sono più distanti, sebbene le onde viaggino alla stessa velocità nello stesso mezzo.

Ora la faccenda si fa interessante. *Un’onda sonora nell’aria è una sequenza di variazioni di pressione*. Un’onda sonora in un solido è invece una vibrazione (infatti il termine “vibrazione” viene usato nel linguaggio tecnico per definire solamente ciò che accade nei solidi).

Tra parentesi: parlerò spesso di rumore e vibrazione assieme, perché parlo di un continuum di energia quando attraversa diverse sostanze. Ad esempio, un’onda sonora che viaggia attraverso l’aria e colpisce un edificio può far vibrare le pareti. Oppure: vibrazioni che attraversano il suolo possono generare vibrazioni in un edificio che a loro volta possono generare onde sonore in una stanza o essere trasmesse all’orecchio attraverso l’osso (per le basse frequenze esistono molte forme di trasformazione dell’energia. L’energia non si attenua o diminuisce molto con la distanza o passando attraverso gli oggetti, ma tende a continuare).

Quando sintomi del genere di cui trattiamo sono studiati in medicina, vengono solitamente associati ad un intervallo di frequenza sonora ridotta, inferiore all’udibilità o appena nella soglia dell’udibilità (riporto i dati di due studi di questo tipo a pag. 40–42). Una ricerca più approfondita sulla sindrome da turbina eolica, potrebbe dimostrare che anche alcuni suoni di frequenza più alta, emessi dalle turbine, provocano i sintomi. Tuttavia il colpevole principale, per lo meno da studi su sintomi simili, sembrerebbe essere il rumore a bassa frequenza.

L’intensità è altrettanto importante. Gli esperti in acustica dell’industria eolica sostengono che poiché il rumore a bassa frequenza delle turbine è inferiore alla soglia umana di udibilità in aria, è anche troppo debole per avere degli effetti sulla salute. Agli esperti in acustica viene insegnato *“Se non si sente, non può fare male!”*. Questa tuttavia è un’eccessiva semplificazione della funzionalità dell’organismo (come descritto sopra, nel paragrafo relativo al modo in cui il suono stimola i riflessi vestibolari). Gli standard di sicurezza sul rumore si basano sulla protezione delle orecchie degli individui dal forte rumore che potrebbe danneggiare l’udito, ma non tengono conto degli altri effetti nocivi dei livelli sonori bassi (ad es. come riportato nella vasta documentazione sul rumore notturno, sugli ormoni dello stress e sulle variazioni cardiovascolari).

Se osserviamo innanzi tutto i sintomi, la questione del rumore nella sindrome da turbina eolica diventa semplice. I sintomi delle persone appaiono e scompaiono. Gli esperti in acustica devono misurare i livelli di rumore alla comparsa dei sintomi e confrontarli con i livelli di rumore alla scomparsa dei sintomi. In questo modo potranno determinare esattamente *quali frequenze* a *quali intensità* sono la causa dei sintomi.

Di seguito, dalla pagina 40–42, viene riportato l'esempio di due resoconti pubblicati da esperti tedeschi che studiano il controllo del rumore e che collegano i sintomi alle misurazioni del rumore. In entrambi i casi, i sintomi (tra l'altro molto simili a quelli della sindrome da turbina eolica) erano causati da un rumore a frequenza molto bassa. In uno dei casi, il rumore è stato identificato, ma non la sua origine, nell'altro l'origine è stata attribuita al grande ventilatore di un edificio.

Torniamo al mio corso intensivo sul rumore. La risonanza è quello che accade alla struttura di una chitarra o di un violino quando una corda viene pizzicata o disturbata da un archetto. È simile all'eco in uno spazio. Alcune lunghezze d'onda rimbalzano avanti e indietro molto efficacemente, considerate le dimensioni di tale spazio. Le pareti dello spazio tendono a vibrare a determinate frequenze e se la frequenza naturale della vibrazione della parete corrisponde alla frequenza del suono rimbalzante, la parete stessa (della chitarra o del violino) può aggiungere "vigore" alle onde sonore alla sua "frequenza risonante", rendendo queste frequenze più intense.

Tutto questo assomiglia molto a quando si fa dondolare un'altalena. (Lo abbiamo fatto tutti da bambini). Il dondolio è una specie di funzione d'onda, come il suono, con tanto di frequenza e ampiezza. La frequenza dell'altalena sarebbe il numero di volte al minuto in cui si muove in avanti e indietro. Le frequenza dipende anche dalla lunghezza della corda. Un'altalena con una corda corta dondola più velocemente. L'ampiezza equivale all'altezza raggiunta dal bambino mentre dondola. La risonanza corrisponde al bambino capace di aumentare l'oscillazione (aggiungendo un po' di energia al movimento) proprio al momento giusto per aumentare l'ampiezza (dondolio più alto). La frequenza rimane la stessa, ma se il bambino spingendo aggiunge energia, dondola sempre più in alto.

Il bambino che aumenta il dondolio è simile alla parete di una camera di risonanza, dà una piccola spinta per "ondeggiare" esattamente al momento giusto.

Bene, la lezione sul rumore è terminata. Applichiamola ora alla sindrome da turbina eolica.

Le risonanze avvengono negli spazi e nelle parti solide, ma flessibili o elastiche del corpo, ad esempio lungo la colonna vertebrale. Diverse parti del corpo presentano diverse frequenze di risonanza. Molte di queste avvengono a bassa frequenza. Quando un'onda sonora o una vibrazione colpisce il corpo c'è una maggiore probabilità che si inneschino vibrazioni in una parte del corpo con una frequenza di risonanza corrispondente.

Nella sindrome da turbina eolica, un'importante risonanza del corpo è la risonanza dello spazio toracico e addominale. La parete toracica si compone di muscoli elastici, ossa, cartilagine, tendini e legamenti che danno al torace un'elasticità naturale e che viene usata nella respirazione. Il corpo ha bisogno di energia per espandere il torace ed inspirare, ma gran parte della forza necessaria per espirare, avviene senza sforzo grazie all'elasticità del torace.

Una parte importante del meccanismo di respirazione è il muscolo del diaframma che sta alla base del torace ed ha una forma a cupola, come la testa di un uovo. Quando si inspira il diaframma si ritira e amplia lo spazio toracico, comprimendo lo spazio addominale. Lo spazio addominale è molto morbido e flessibile, con la parte anteriore composta da sottili strati di muscolo, pelle e altro tessuto morbido, senza ossa o cartilagine. Inspirando, lo stomaco sporge in avanti. Quando il muscolo del diaframma si rilassa, riassume la sua forma a cupola e spinge fuori l'aria. Elasticità naturale in azione.

Quindi, quando la pressione dell'aria entra nei polmoni, alle onde di pressione serve poca energia per far vibrare questo sistema che è particolarmente mobile. Il diaframma vibra ad una frequenza di 4–8 volte al secondo (Hz significa "volte al secondo"). La frequenza di 4–8 Hz è un rumore a bassa frequenza o un infrasuono, vale a dire, inferiore alla soglia di udibilità.

Non solo il diaframma vibra, ma anche l'intera massa degli organi interni dell'addome oscilla verso l'alto e verso il basso, vicino e lontano dai polmoni. Uno dei maggiori organi addominali, il fegato, è connesso al lato inferiore del diaframma.

Anche altre parti del corpo possono avere una risonanza, ad esempio gli occhi (bulbi circondati dalle ossa e poco materiale denso interno) e la scatola cranica. I ricercatori che hanno studiato l'orecchio interno e hanno scoperto il picco di 100 Hz per la risposta vestibolare, parlano di risonanza del cranio a 500 Hz. A questo livello il cranio "tintinna". Perfino la colonna vertebrale ha una frequenza di risonanza. La spina è elastica e se viene fatta vibrare ad una particolare frequenza, può generare una vibrazione verticale per tutta la propria lunghezza.

Anche le parti più piccole del corpo, come gli organi dell'orecchio interno, hanno risonanze e risposte di picco che dipendono da dimensione, rigidezza e pressione del liquido in uno dei lati, come la risposta al picco di 100 Hz dell'utricolo.

Insomma, ciò che viene definito semplicemente *rumore* può avere un forte impatto su molte strutture e cavità interne. Vedremo l'importanza di tutto questo nella discussione qui di seguito.

Prima di passare alla sezione sui metodi, vorrei accennare brevemente alle misurazioni della potenza sonora e le definizioni di "pesatura A" e "pesatura C" (A-weighting e C-weighting). È difficile misurare l'intensità (energia) del suono in modo accurato e riproducibile, in particolare a basse frequenze. I network di pesatura A e C nella strumentazione fonometrica selezionano l'energia (intensità) in base alla frequenza. Al fine di ottenere un unico valore per l'intensità del suono, si dovranno sommare le diverse frequenze. Il network di pesatura controlla quanto ogni frequenza contribuisca al numero.

Il network di pesatura A è quello generalmente usato negli studi sul rumore ambientale, forse più per abitudine che per buon senso. È formulato per duplicare la reazione alla frequenza dell'udito umano, attraverso l'aria, l'orecchio esterno, la membrana timpanica e le tre ossa dell'orecchio medio. Questo sistema di orecchio esterno-medio (pesatura A) costituisce un filtro che accentua i toni alti usati nel riconoscimento del linguaggio umano, mentre attutisce o afferra solo in minima parte il contributo dato dai suoni udibili di bassa e media frequenza, e dagli infrasuoni (definiti come 20Hz e inferiori). La pesatura A aumenta lievemente i contributi dei suoni nell'intervallo 1000–6000 Hz (sul pianoforte: da Do due ottave *sopra* Do medio, tasto 64, a Fa# *sulla nota più alta* del pianoforte), riducendo progressivamente i contributi delle frequenze più basse al di sotto di circa 800 Hz (Sol-Sol# 1½ ottava *sopra* Do medio, tasti 59–60, non proprio una nota bassa). A 100 Hz, quando l'organo vestibolare umano fornisce una risposta altamente sensibile alla vibrazione (Sol-Sol# 1½ ottava sotto il Do medio, tasti 23–24), una misurazione con pesatura A cattura solo 1/1000 dell'energia sonora concretamente presente (–30 dB). A 31 Hz (Si, il secondo tasto bianco dalla fine, il tasto 3), una pesatura A coglie solo 1/10.000 dell'energia sonora presente (–40 dB). A10 Hz, una frequenza che in un altro studio ha dimostrato provocare sintomi simili alla sindrome da turbina eolica (vedi oltre, pag. 40–42), una pesatura A coglie solo $10^{-7}$ o un dieci-milionesimo dell'energia sonora presente.

Il network di pesatura C invece, ha una risposta piatta all'intervallo udibile, vale a dire non migliora né riduce il contributo delle diverse frequenze sonore udibili, e una risposta decrescente sotto 31 Hz. A 10 Hz la pesatura C cattura 1/25 dell'energia sonora. Come per la pesatura A, rappresenta uno standard nella strumentazione di misurazione del suono.

La pesatura C è più adatta a descrivere il rumore ambientale, mentre la pesatura A è più adatta a cogliere i suoni acuti, gli stessi suoni che le pareti trattengono, e quindi i suoni che con minore probabilità danno fastidio alla persona che sta dall'altra parte del muro, dove c'è una fonte di rumore. I suoni che attraversano i muri sono bassi, i sottofondi rimbombanti del televisore o le persone che parlano in un'altra stanza, il rumore dei passi o della lavatrice al piano superiore, il rimbombo di uno spazzaneve sulla strada o l'auto con sistema stereo modificato di un giovane ad un isolato di distanza. Questi suoni possono creare perfino nuove vibrazioni nelle pareti e nelle finestre. Sembra strano, ma l'impiego di pesatura A per la determinazione del rumore ambientale (incluse le misurazioni del rumore provocato dalle turbine eoliche) si concentra sulle stesse frequenze che un po' di isolamento farebbe scomparire facilmente.

Ora che sappiamo che toni non udibili, condotti attraverso le ossa a 100 Hz, stimolano il sistema vestibolare umano (come descritto sopra), non è giustificabile usare esclusivamente la pesatura A negli studi sul rumore ambientale. Usata invece in combinazione con la pesatura C, la differenza tra le misurazioni A e C dello stesso rumore offre un modo costante e facilmente disponibile per calcolare la potenza dei suoni di frequenza più bassa nel rumore.

Ottenere un'attrezzatura di misurazione standardizzata con networks A o C, è facile, ma la misurazione della potenza della frequenza sonora più bassa richiede apparecchiature specializzate con modelli non standardizzati. Ma, se vogliamo capire fino in fondo la Sindrome delle Turbine Eoliche, dobbiamo eseguire le misurazioni delle più basse tra le basse frequenze.

## Metodi

Per il protocollo della mia ricerca ho utilizzato la cosiddetta *serie di casi* (in medicina una serie di casi è definita come *un resoconto descrittivo di una serie di individui con lo stesso nuovo problema medico*).

Nella ricerca medica, una *serie di casi* non dispone di gruppi di controllo (cioè confronto). Tuttavia, ho aggiunto una nuova sfumatura al mio studio, basandomi sulla mia formazione nel campo dell'ecologia: sebbene non avessi un gruppo di controllo convenzionale (confronto), ho scelto i soggetti e organizzato il modo di raccogliere informazioni così da essere in grado di confrontare i dati.

Innanzitutto, per definire in maniera appropriata questi episodi come problemi associati alle turbine eoliche ho confrontato come erano le persone *durante l'esposizione alle turbine e come erano quando non vi erano esposti, specificando che "non esposti" indica sia prima che dopo aver vissuto vicino alle turbine. Tutti i miei soggetti hanno notato la comparsa dei disturbi subito dopo l'attivazione delle turbine vicino alle loro abitazioni e osservato la scomparsa dei problemi quando si allontanavano dalle turbine.*

In un secondo momento, ho confrontato le persone con particolari sintomi con quelle senza sintomi, controllando poi, per determinare i fattori di rischio per la salute, se le differenze fossero influenzate dall'età, da patologie pre-esistenti, ecc.

Un terzo tipo di confronto è stato implicitamente eseguito su tutta la popolazione generale. Ad esempio, la Dott.ssa Harry ed io abbiamo raccolto dati in modo simile, intervistando adulti colpiti dalla sindrome, ed entrambe abbiamo ottenuto dei risultati che ci indirizzavano verso una fascia di età intorno ai 50 anni o più. Ciò ha suggerito che le persone più anziane tendono ad essere maggiormente colpite, poiché questo gruppo è rappresentato da un gran numero di persone nella nostra campionatura (questo è logico dal punto di vista medico, e corrisponde anche a chi è più infastidito dal rumore in altri contesti, non connessi con le turbine).

In più, il mio studio comprende un numero maggiore di persone soggette ad emicrania che non la popolazione in generale e ciò sembra implicare che, come le persone anziane, anche le persone affette da emicrania sono più sensibili alle turbine.

Vediamo ora come studi epidemiologici sulle turbine si potrebbero presentare e che cosa potrebbero dimostrare, prescindendo dal mio metodo della *serie di casi*. Esistono diversi tipi di studi epidemiologici.

In uno studio prospettico o longitudinale, il ricercatore inizia con la definizione di due gruppi identici da studiare, *prima* che entrambi vengano esposti ad un (ipotetico) agente intossicante o terapeutico. Un gruppo viene chiamato gruppo di studio e l'altro gruppo di controllo. Il gruppo di studio comprende gli individui che saranno esposti all'agente, mentre il gruppo di controllo sarà completamente identico al gruppo di studio per età, sesso, reddito, educazione, ecc.

Con l'avvio dell'esposizione, i ricercatori controllano gli eventi di entrambi i gruppi, eseguendo confronti, statistiche e formulando le loro conclusioni.

Gli studi prospettici vengono utilizzati quando sussiste la probabilità che l'esposizione possa guarire le persone, come negli studi clinici di nuovi farmaci. Il progresso dei soggetti di ogni gruppo viene monitorato attentamente e i dati sono analizzati nel corso dello studio per verificare che l'agente presumibilmente terapeutico non sia in realtà dannoso (questo può talvolta accadere e in tal caso lo studio clinico viene interrotto prima del suo completamento).

Gli studi prospettici possono essere utilizzati anche quando gli individui si espongono da soli a un agente nocivo, ad esempio al fumo, oppure quando accade qualcosa programmata per altri motivi, ad esempio la chiusura di un aeroporto in un luogo e l'apertura di uno nuovo in un altro luogo (uno studio reale che ha dimostrato gli effetti dannosi per la lettura, nel caso di bambini esposti al suono). Tuttavia non sarebbe etico elaborare uno studio che esponga gli individui a qualcosa che è già sospettato di essere dannoso.

Uno studio trasversale è diverso da uno studio prospettico o longitudinale. Uno studio trasversale confronta gli individui esposti (*studio*) a quelli non esposti (*controllo*) durante lo stesso periodo, individui che risiedono o lavorano in posti diversi, a seconda del luogo in cui si verifica l'esposizione. Scegliere la popolazione da studiare è difficile, perché i due gruppi devono necessariamente essere identici in tutto eccetto che nell'esposizione. Un altro punto difficile è decidere cosa calcolare e quale procedure utilizzare. Se prendiamo il caso delle turbine eoliche il tipo di interviste approfondite che ho impiegato non sarebbe adatto al campionamento di centinaia o migliaia di persone. D'altro canto, i sondaggi postali, nonostante raggiungano potenzialmente un'intera popolazione, presentano dei problemi di scarsa partecipazione e possibile scorretta interpretazione delle domande che introducono errori. Le domande dei sondaggi sono spesso distaccate e semplificate per garantire che tutti le comprendano nello stesso modo e per evitare di suggerire qualcosa.

Alla fine della Relazione Per Medici, ho discusso su quale tipo di studi sarebbero attuabili o auspicabili per la fase successiva della ricerca, in particolare studi strutturati in modo da combinare dati specifici e realistici sullo stato di salute con un'ampia copertura della popolazione.[4] Una selezione di paesi europei sarebbe l'ideale per questo tipo di studio, è cioè quelli che hanno turbine eoliche e sistemi sanitari unificati nei quali la diagnosi di ogni visita presso qualsiasi medico è registrata nello stesso database centrale.

Tornando alla relazione. Il problema di ogni studio clinico è comprendere quali nuovi sintomi sono causati da una nuova esposizione e quali non lo sono. In uno studio epidemiologico questo aspetto viene risolto utilizzando dei gruppi paralleli, con un gruppo non esposto. Non avendo le risorse per condurre uno studio simile, ho insistito che per i soggetti del mio studio vi fosse un periodo di post-esposizione, vale a dire un periodo conseguente all'esposizione durante il quale i sintomi sono scomparsi. *La sindrome da turbina eolica viene definita solo dalla comparsa dei sintomi durante l'esposizione e la scomparsa degli stessi al termine dell'esposizione*. Forse non sono stati individuati tutti gli effetti sulla salute causati dall'esposizione alle turbine eoliche, dati i limiti della struttura del mio studio, ma è stata indubbiamente identificata una serie significativa di sintomi.

Mi sono avvalsa inoltre di un altro metodo per creare dei gruppi di confronto. Durante le interviste, ho raccolto informazioni su tutti i membri della famiglia, su di loro, sui loro figli e sui membri disabili che non hanno potuto partecipare alle interviste. Così ho scoperto che non tutti nella stessa famiglia venivano colpiti nel medesimo modo, nonostante vivessero nella stessa abitazione e alla stessa distanza dalle turbine. Inoltre, ho confrontato persone affette e non affette da sindrome, per capire quali parti della loro storia medica precedente all'esposizione potevano indicare quali tipi di sintomi si sarebbero manifestati durante l'esposizione.

Tenendo questo in mente, guardate in quale modo ho eseguito la selezione dei soggetti del mio studio:

1) almeno un membro della famiglia presentava gravi sintomi dovuti alla vicinanza delle turbine

4. Pierpont (2009).

2) la famiglia aveva lasciato l'abitazione o trascorso un periodo lontano da essa, sufficiente ad alleviare i sintomi

3) gli individui intervistati dovevano descrivere chiaramente, nei particolari e con coerenza che cosa era loro successo, in quali condizioni e quando

4) tutti risiedevano nelle vicinanze di turbine attivate tra il 2004 e il 2007

5) se già trasferiti in un'altra località al momento dell'intervista, dovevano essere trascorse meno di 6 settimane dal trasloco

6) avevano intrapreso azioni drastiche per proteggersi dall'esposizione alle turbine (generalmente identificata come rumore):

   a) alcuni si erano trasferiti

   b) alcuni avevano acquistato una seconda casa nell'attesa di andare via

   c) alcuni avevano lasciato la propria abitazione per mesi

   d) una famiglia aveva ristrutturato la casa nella speranza di attenuare il rumore

   e) un uomo aveva iniziato a dormire nella propria cantina

Un punto finale. Questo simbolo a svolazzi $\chi^2$ si chiama "chi quadrato". Non spaventatevi! Si tratta solo di un test statistico, che illustrerò con un esempio.

1) c'è un gruppo di persone.
2) si classificano come alto o bassi, con occhi azzurri o bruni.
3) una statistica "chi quadrato" ($\chi^2$) permette di dire se gli occhi azzurri sono associati in qualche modo al fatto di essere alti o bassi, eccetto che in un modo causale (non associato)
4) siccome tutti sanno che avere occhi azzurri o bruni non ha niente a che fare con l'essere alti o bassi, con un calcolo statistico $\chi^2$ su, mettiamo, 20 persone, per ogni persona classificata in ambedue queste categorie (colore degli occhi e altezza) si otterrebbe un risultato non significativo.
5) fine della spiegazione

Non era poi così difficile, no?

Vedrete che leggendo la mia relazione clinica, incontrerete valori chiamati p (probabilità) tra parentesi, assieme a valori $\chi^2$.[5] Niente panico! P è la probabilità che la relazione tra le due variabili (colore degli occhi e altezza) non sia significativa. In altre parole, essere alti non aumenta la probabilità di avere gli occhi di uno o dell'altro colore, ovvero l'altezza e il colore degli occhi non sono affatto correlati.

I valori di p variano tra i numeri bassi vicino a 0 e 1. I valori bassi indicano *una forte correlazione tra le due variabili*. "Basso" significa minore di 0,05. "Molto basso" o minore di

5. Pierpont (2009).

0,01 implica una probabilità ancora maggiore di casualità delle due variabili (ad es. colore degli occhi e altezza).

D'accordo, ora potete fare un respiro, abbiamo finito con la matematica. Questo è il modo in cui identifico i "fattori di rischio" nel mio studio (il fattore di rischio è un elemento nella storia medica o nel loro modo di essere che rende gli individui suscettibili, in questo caso, alla sindrome da turbina eolica, quando sono esposti alle turbine). Ho applicato poi l'analisi di $\chi^2$. Ad esempio, ho considerato se uno dei soggetti era affetto o no da tinnito durante l'esposizione alle turbine. Ho controllato se una persona era stata in precedenza esposta a rumore industriale o no, e ho scoperto che in tal caso sussiste una relazione significativa.

Torneremo su questo, qui di seguito, nella sezione sui Risultati.

## Risultati

Lo studio dimostra che quelli elencati qui sotto sono i sintomi più significativi della sindrome da turbina eolica.

1) Innanzitutto *quasi tutti hanno disturbi del sonno.* In relazione a questa osservazione risultano due modalità particolarmente interessanti.

   a) La prima è caratterizzata da elementi di "paura" al momento di risveglio. Da citare sono ad esempio terrori notturni infantili e adulti che si svegliano di colpo, allarmati e in stato d'ansia. Gli adulti riportano di aver sentito una compulsione a controllare se qualche estraneo fosse entrato in casa, pur sapendo di essere stati svegliati dal rumore delle pale eoliche. Altri si svegliano con il batticuore e con difficoltà di respirazione.

   b) La seconda modalità è la tendenza ad urinare spesso durante la notte. Per gli adulti ciò ha comportato doversi alzare frequentemente e per uno dei bambini ha significato diuresi notturna (scomparsa una volta lontano dalle turbine).

   Non è stato necessario indagare sui fattori di rischio per i disturbi del sonno, dato che tutti gli intervistati presentavano gli stessi sintomi.

2) *Mal di testa*. Oltre la metà dei soggetti dello studio ha sofferto episodi di mal di testa, peggiori di quelli avuti prima dell'esposizione alla turbina. Il tipo di mal di testa presentava maggiore frequenza, gravità e durata rispetto a quello normale.

   La metà dei soggetti che presentavano un peggioramento del mal di testa soffre di un disordine emicranico pre-esistente (tendenza ereditaria a gravi mal di testa con vertigini, nausea, alterazioni visive, tendenza ad evitare la luce, il rumore e il movimento). Tutti i bambini compresi nello studio colpiti da mal di testa durante l'esposizione alle turbine, erano affetti da disordine emicranico oppure erano i figli di soggetti affetti da emicrania.

Circa metà degli adulti colpiti da mal di testa nel corso dell'esposizione non presentava fattori di rischio identificabili. Ciò sembra indicare che chiunque può essere colpito da gravi mal di testa durante l'esposizione alle turbine.

3) *Sintomi auricolari.* Il tinnito è un sintomo dominante nella fase di esposizione. Tinnito: un fischio, suono sordo, rumore di cascata in uno o ambedue gli orecchi o addirittura un ronzio che sembra essere all'interno della testa. Fattori di rischio per il tinnito durante l'esposizione sono:

   a) tinnito prima dell'esposizione (peggioramento del tinnito durante l'esposizione)

   b) perdita parziale dell'udito prima dell'esposizione

   c) precedente esposizione al rumore industriale

   Tutto ciò sembra indicare danni precedenti all'orecchio interno dovuti a esposizione a rumore, a chemioterapia, ad alcuni antibiotici o ad altre cause.

   Alcune persone hanno sentito dolore, schiocchi e sensazione di pressione nelle orecchie e variazioni dell'udito.

4) Il quarto sintomo significativo è stato da me definito VVVD, ovvero *disturbo vestibolare vibratorio viscerale.* Ritengo che si tratti di un nuovo sintomo patologico. Prima di continuare, dovreste leggere i resoconti sui sintomi VVVD nella Tabella 1 di seguito, in modo di avere un'idea sui sintomi riportati dagli intervistati. Una volta ottenuto un quadro generale dei sintomi di VVVD, discuteremo su come si presentano.

   a) sensazione di pulsazione, tremito o vibrazione interna. Alcuni hanno l'impressione che la respirazione sia difficoltosa e hanno un senso di costrizione.

   b) Nervosismo, tremiti, paura. Sentire la necessità di fuggire o di controllare se la casa è sicura.

   c) Tremore

   d) Battito cardiaco accelerato

   e) Nausea

   *I VVVD sono essenzialmente i sintomi di un attacco di panico associato alla sensazione di movimento del torace nelle persone che non ne hanno mai sofferto in precedenza* (nessuno dei miei soggetti aveva mai avuto attacchi di panico).

   Poiché i sintomi del VVVD sono simili agli attacchi di panico, ho cercato un nesso tra questi e la presenza di un qualsiasi tipo di ansia, depressione o disordine mentale. Non ho trovato nessuna correlazione, *tuttavia ho individuato un collegamento particolarmente significativo tra i VVVD e una preesistente* *sensibilità al movimento* (mal d'auto, mal di mare o ricorrenza precedente di vertigini).

Su 21 pazienti adulti (22 anni e oltre) presi in considerazione nello studio, 14 hanno sofferto di VVVD. I due bambini dello studio sembravano essere affetti da disturbi simili. Non sappiamo esattamente che cosa sentissero, ma si svegliavano ripetutamente la notte, strillavano ed era molto difficile calmarli e farli tornare a letto o riaddormentare. Anche i 2 bambini di 5 anni presi in considerazione in questo studio si sono svegliati in lacrime durante la notte.

5) *Concentrazione e memoria.* Quasi tutti gli intervistati hanno problemi di concentrazione e di memoria. Le situazioni più serie sono collegate a una generale mancanza di energie e di motivazione. È importante notare che molti dei soggetti hanno addirittura perduto delle abilità che padroneggiavano prima dell'esposizione alle turbine e che gli insegnanti hanno notato l'insorgere di problemi nel rendimento scolastico dei bambini e hanno inviato messaggi ai genitori (consultare i resoconti sui sintomi legati alla concentrazione e alla memoria nella Tabella 2 sottostante, nonché i resoconti della convalescenza da tali sintomi nella Tabella 3).

   In alcuni casi i problemi di concentrazione si sono risolti non appena si sono allontanati dalle pale eoliche o addirittura quando le pale sono state orientate in un'altra direzione. In altri casi i problemi non sono scomparsi subito, ma si sono risolti gradatamente in un certo periodo di tempo. Indubbiamente la privazione di sonno influisce notevolmente su memoria e concentrazione, ma queste modalità di guarigione sembrano indicare l'esistenza di un altro tipo di influssi che potrebbero essere spiegati con l'effetto del disturbo vestibolare su varie forme di pensiero. (vedere Discussione, di seguito).

6) Ulteriori sintomi fondamentali sono *irritabilità e rabbia*, presentati da gran parte dei soggetti, tra cui anche i bambini. Spesso è stato il comportamento dei bambini, i problemi scolastici, la loro irritabilità e la perdita di controllo nelle relazioni sociali a spingere le famiglie ad abbandonare le loro case e ad allontanarsi dalle turbine.

7) In gran parte dei soggetti si è osservata *stanchezza*, talvolta un senso di pesantezza e la perdita della capacità di divertirsi e di motivazione nelle attività quotidiane. Nella maggior parte dei casi anche questi sintomi sono scomparsi non appena si sono allontanati.

8) Ho infine, compilato una lista di sintomi di cui gli intervistati mi hanno parlato, ma che richiederebbero altri metodi di studio (visite mediche e test e controlli sistematici dei casi) per scoprire se sono connessi alle pale eoliche. Questi sintomi sono meno frequenti e comprendono *infezioni delle vie respiratorie inferiori* (bronchite, polmonite e pleurite), insoliti nelle persone colpite, quali peggioramento dell'asma, liquido o infezioni dell'orecchio medio e ictus oculare.

   Per il momento non è stato possibile trovare un nesso, ma ritengo che questi sintomi dovrebbero essere presi in considerazione in uno studio su vasta scala in relazione agli effetti delle turbine eoliche sulla salute.

## Discussione

Questa sezione riguarda il meccanismo della sindrome e le idee che ho raccolto dalla letteratura medica e dai miei colleghi. È la sezione più interessante, in cui si riconoscono le connessioni.

Fin dall'inizio ho considerato i sintomi della sindrome da turbine eoliche come un insieme coerente, perché conoscevo già gli effetti chiamati *vertigini emicraniche* o *il senso di capogiro associato all'ansia da emicrania.*

L'emicrania non è solo un terribile mal di testa, ma una sindrome neurologica alla quale si associano ulteriori sintomi specifici. Mio marito ha sofferto di emicrania fin dall'adolescenza, ma mai di mal di testa. Ha capogiri, stanchezza e macchie cieche (scotomi). Deve sdraiarsi e attendere che passi. Alcuni anni fa, ebbe un episodio di vertigini nauseanti (vertigini e senso di sbandamento), tinnito e ansia, che si trasformarono in depressione. La persona che offrì una diagnosi fu l'otorinolaringoiatra, al quale ho dedicato questo libro, il Dott. Dudley Weider.

Il Dott. Weider mi ha spiegato che emicrania, vertigini, tinnito e ansia presentano un nesso neurologico, ed è riuscito a curare mio marito con successo. Vorrei anche aggiungere che mio marito è sempre stato sensibile al movimento, un aspetto condiviso da circa la metà degli individui colpiti.

Di conseguenza, quando ho sentito parlare dei sintomi della sindrome da turbina eolica, li ho immediatamente riconosciuti come un complesso di sintomi correlati. Avrei voluto condividere questa relazione con il Dott. Weider, ma purtroppo è venuto a mancare. Tuttavia, ho avuto il piacere di condividerla con un gruppo di suoi colleghi specialisti (vedi l'elenco dei relatori e lettori di questa relazione. Si tratta di una Festschrift in onore del Dott. Weider). I colleghi mi hanno insegnato molti aspetti importanti relativi all'equilibrio e all'orecchio interno, che ho incorporato in questo libro.

Il dott. Lehrer e il dott. Black considerano il complesso di sintomi della sindrome da turbina eolica simile ai sintomi provocati da un disturbo dell'orecchio interno, denominati idrope endolinfatico(abbreviato EH). Nel caso dell'EH i sintomi possono essere sempre presenti oppure variare d'intensità (senza che le cause siano note). Nel caso della sindrome da turbina eolica, i sintomi vanno e vengono a seconda se i soggetti colpiti sono vicini o lontani dalle turbine o anche, se le turbine producono un certo tipo di rumore o sono rivolte in una certa direzione.

EH comprende anche il morbo di Meniere e la fistola perilinfatica (fuoriuscita di liquido dall'orecchio interno all'orecchio medio), comporta una distorsione della pressione tra i due compartimenti di liquido nell'orecchio interno: l'endolinfa (nel labirinto membranoso) e la perilinfa (intorno al labirinto membranoso, tra i canali ossei). Ciò causa equilibrio incerto e malsicuro e, spesso, segnali acustici distorti inviati al cervello.

Oltre alle vertigini e ai problemi uditivi, l'idrope endolinfatico è noto agli specialisti per essere connesso con problemi relativi alla memoria a breve termine, alla concentrazione, alla capacità di eseguire più cose contemporaneamente (multitasking), aritmetica e lettura. Possono talvolta verificarsi anche mal di testa, disturbo del sonno e forti carenze della prestazione mentale rispetto alle condizioni normali.

Tutto questo suona come la sindrome da turbina eolica senza turbine.

Un aspetto interessante è che l'esposizione al rumore a bassa frequenza (nelle cavie per un breve periodo, ad intensità elevata ma non traumatica) provoca l'idrope endolinfatico temporaneo (immaginate allora l'esposizione costante al rumore a bassa frequenza e intensità negli umani?). L'esposizione sperimentale al rumore a bassa frequenza ha aumentato negli animali la sensibilità al rumore, la cosiddetta "iperacusia", un altro effetto osservato nello studio sulla sindrome da turbina eolica. Gli individui colpiti da idrope endolinfatico avvertono un senso di otturazione o pressione nell'orecchio, cosa che rappresenta un comune sintomo comune anche nel mio studio.

Arriviamo dunque al sistema di equilibrio e al suo funzionamento. L'equilibrio è un sistema complesso che coinvolge numerose aree del cervello e accoglie molti segnali sensoriali dall'intero organismo. Gli altri sensi possiedono solo un tipo di input, il sistema di equilibrio ne ha quattro.

Parlando di sistema di equilibrio intendo:

a) in quale modo il corpo mantiene la posizione eretta e

b) *qualsiasi aspetto legato alla consapevolezza del movimento e della posizione*

Ad esempio, il sistema di equilibrio è particolarmente attivo nel caso di capriole e gli avvitamenti nei tuffi e nella ginnastica, anche se lo sportivo non si trova in posizione dritta.

Perché tutta quest'attenzione al sistema dell'equilibrio? Perché ritengo che gli *individui con predisposizione ad uno squilibrio siano particolarmente sensibili alla sindrome da turbina eolica*. È dunque importante chiarire in che modo nelle persone si suscitano squilibri, per capire in qual modo le variazioni di pressione dell'area (suoni) o le vibrazioni delle turbine eoliche inneschino un senso di movimento fuori dal normale o di instabilità in persone che ne hanno la predisposizione.

Come accennato, i segnali di *movimento* e *posizioni* ci giungono da quattro sistemi distinti dell'organismo, e sono integrati dai centri dell'equilibrio (vestibolari) nel cervello:

1) occhi (sistema visivo)

2) organi di percezione di movimento e posizione nell'orecchio interno (sistema vestibolare)

3) recettori di stiramento dai muscoli e dalle articolazioni di tutto il corpo e recettori del tatto sulla pelle (sistema somatosensoriale)

4) recettori di stiramento e di pressione associati agli organi del torace e dell'addome

*Per mantenere l'equilibrio il sistema richiede che almeno 2 dei primi 3 canali (visivo, vestibolare e somatosensoriale) siano sempre in funzione e che forniscano dati concordanti.* Fate attenzione a questo punto, perché è particolarmente importante. Lo potremmo definire *la legge dell'equilibrio.*

Ad esempio, negli anziani gli organi vestibolari dell'orecchio interno tendono a non funzionare bene. Se l'orecchio interno non invia i segnali corretti, le persone si devono affidare a ciò che vedono e alla percezione dei piedi e delle gambe per mantenere l'equilibrio.

Perché il senso dell'equilibrio funzioni però, almeno due canali devono mandare segnali concordanti, quindi queste persone hanno difficoltà trovandosi al buio.

Se avete un buon senso dell'equilibrio, tentate questo esperimento: stando su un piede, percepite tutti i piccoli movimenti correttivi del piede e della caviglia per mantenervi in posizione eretta. Gli individui con un equilibrio normale possono rimanere su un piede a tempo indeterminato.

Ora chiudete gli occhi e fate attenzione dopo quanto tempo dovete mettere l'altro piede a terra per evitare di cadere.

*In questa condizione è impossibile mantenere l'equilibrio, perché si è privati della visione e dell'input somatosensoriale delle gambe. Un solo sistema, quello vestibolare dell'orecchio interno non è sufficiente* (se non avete un buon senso dell'equilibrio, anche mettendo entrambi i piedi a terra e chiudendo gli occhi, potreste sentire la differenza).

Il modo in cui questa regola clinica integra il nuovo quarto canale delle informazioni di equilibrio, gravità viscerale e percezione del movimento, deve essere ancora definito. È possibile che i centri vestibolari del cervello considerino anche la quantità e la qualità delle informazioni provenienti da ciascun canale e non solo se un canale è attivo. Ad esempio, in assenza di informazioni visive (occhi chiusi o al buio), le informazioni extra somatosensoriali provenienti anche da un dito sulla parete o sulla ringhiera possono essere sufficienti alla sensazione di stabilità e benessere di un individuo. Allo stesso modo è più semplice mantenere l'equilibrio su due piedi che su uno. Mantenersi in equilibrio è più difficile se i piedi sono su una linea, uno dietro all'altro su un'asse di equilibrio o, peggio, su una fune mobile e instabile. Queste situazioni limitano o alterano le informazioni somatosensoriali provenienti da piedi e gambe, ma non le annullano completamente.

Le varianti della funzione di equilibrio sembrano rientrare in quattro grandi categorie:

1) *La prima variante è la prima infanzia*. I bambini piccoli cadono spesso. Con la crescita, l'equilibrio migliora e sono in grado di eseguire movimenti più complessi senza cadere. Nella prima infanzia, i bambini stabiliscono una corrispondenza dell'intero sistema sensoriale con il resto del mondo. Ad esempio, un bebè elabora la distanza che il proprio braccio deve percorrere per toccare qualcosa e il suo aspetto e la sua consistenza. In questo modo acquisisce il senso della distanza, legando tale concetto ai sensori visivi e ai recettori di stiramento coordinati di braccio e spalla. Tale processo di apprendimento in cui le parti del corpo si trovano in uno spazio, attraverso attività sempre più complesse, si protrae per tutta l'infanzia. All'inizio, i bambini sono maggiormente predisposti a disturbi di equilibrio.

2) *La seconda causa di variazione dell'equilibrio sono differenze nel processo centrale (nel cervello) dei segnali di equilibrio e movimento*. Gli individui sensibili al movimento, la metà delle persone che soffrono di emicrania, ma anche individui alti, hanno problemi ad elaborare correttamente i segnali provenienti dai diversi canali sensoriali dell'equilibrio. Il loro cervello tende a concedere eccessiva o troppo scarsa attenzione ad alcuni canali. Ad esempio, in un individuo affetto da vertigini emicraniche e tinnito, come mio marito, i segnali dall'orecchio interno possono rivelarsi troppo intensi. Di conseguenza il cervello li deve ridurre e deve adattarsi all'eccessiva intensità di un segnale. Oppure potrebbe succedere che i segnali non siano troppo forti, ma distorti, così che il cervello li deve, a maggior ragione, ridurre al massimo. Abbassando i segnali dell'orecchio interno, si diventa più dipendenti dal canale visivo o da quello somatosensoriale. Le persone che per mantenere l'equilibrio dipendono dalla vista hanno spesso paura dell'altezza (come mio marito). Ciò accade perché a distanza le informazioni visive di posizione sono ridotte (ad esempio, minore informazione retinica e variazione della parallasse con il movimento). La paura è connessa a questa esperienza perché instabilità o insicurezza sulla posizione nello spazio provocano paura, a causa di un riflesso neurologico (torneremo su questo di seguito). Chi invece dipende dai segnali di superficie, potrebbe trovarsi in difficoltà se la superficie è scivolosa, perché si affida ai segnali e alle informazioni di posizione provenienti dai suoi muscoli e articolazioni. Questi segnali vengono distorti dalla superficie scivolosa.

3) *La terza causa di difetti o di disfunzione dell'equilibrio sono danni all'orecchio interno e malformazioni congenite o di sviluppo dell'orecchio interno.* Il danno può essere stato causato da rumore acuto, esposizione ad esplosioni, lesioni alla testa e al collo (anche minori come il 'colpo di frusta' o iperflessione ed iperestensione cervicale), complicazioni derivanti da infezioni croniche o ricorrenti dell'orecchio medio durante l'infanzia o esposizione ad alcune sostanze chimiche (antibiotici aminoglicosidici o chemioterapia con cisplatin, ad esempio), idrope endolinfatico, patologia dell'orecchio interno descritta sopra, inclusi la malattia di Meniere e la fistola perilinfatica. Le patologie autoimmunitarie come il lupus (attacco di anticorpi ad altre parti del corpo). Anche difetti di formazione delle ossa e dei canali dell'orecchio interno, eventualmente in combinazione con traumi o altre lesioni, possono causare disturbi.

4) *La quarta causa di difetti o disfunzione dell'equilibrio è l'età avanzata.* Sembra che esista un deterioramento della funzione dell'orecchio interno in individui di età superiore ai 50 anni, naturalmente in gradi diversi a seconda delle persone.

Arriviamo ora *alla disfunzione dell'equilibrio compensata o, al contrario, non compensata*. Le persone affette da una disfunzione di equilibrio ma in grado di compensare, si sentono bene, stanno in equilibrio e il loro corpo si sente a suo agio nella sua posizione nello spazio. Se però sono confrontati con un'ulteriore disturbo o una distorsione proveniente da un secondo canale, perdono l'equilibrio, si sentono malsicuri, hanno capogiri, vertigine o mal di mare. In tal caso parliamo di *disfunzione dell'equilibrio non compensata*, si sarà sbilanciati, malfermi o confusi oppure affetti da vertigini e da intolleranza al movimento. I centri vestibolari o dell'equilibrio nel cervello che integrano tutti i segnali provenienti dal sistema di equilibrio, riescono ad ignorare o sopprimere i segnali di un canale che non corrisponde agli altri, *ma non sono in grado di farlo se i canali disturbati sono due*. Un unico canale funzionante non è sufficiente.

Ritengo che le persone affette da sindrome delle turbine eoliche, abbiano in condizioni normali (prima dell'esposizione alle turbine, in normale condizioni di salute), un problema di equilibrio compensato, come in uno dei quattro punti discussi sopra. *L'esposizione alle turbine eoliche peggiora la situazione, poiché il cervello non può ignorare i segnali di disorientamento provenienti contemporaneamente da due canali*. Almeno un gruppo di falsi segnali proviene dalle turbine, mentre il secondo segnale problematico deriva da una delle quattro categorie appena descritte.

Ma come è possibile che segnali di equilibrio sbagliati arrivino dalle turbine? *Succede se disturbano uno dei quattro canali sensoriali di equilibrio, inducendo tale canale ad inviare segnali discordanti che i centri vestibolari non riescono ad integrare, o se disturbano contemporaneamente diversi canali.*

I quattro tipi di disturbo dei quattro canali di equilibrio sono:

1) Disturbo dell'orecchio interno (organo vestibolare): il rumore o la vibrazione a bassa frequenza stimola gli otoliti, attivando i centri vestibolari (equilibrio) del cervello (come descritto nella prima parte di questo capitolo) e producendo illusione di movimento, instabilità, irrigidimento dei muscoli del collo con il riflesso vestibolo-collico e altri sintomi. In presenza di preponderanti sintomi dell'orecchio (quali pressione, schiocchi, tinnito, dolore o alterazioni dell'udito), sospetto che i disturbo degli organi vestibolari rappresenti la causa maggiore.

2) Disturbo visivo: individui con sensibilità visiva sono disturbati dalla percezione dall'ombra semovente delle pale sul paesaggio (che dovrebbe essere statico) o dallo sfarfallio della luce solare all'interno degli edifici, quando l'ombra delle pale passa sulle finestre. Due persone, entrambe donne adulte soggette a vertigini in condizione normali, hanno mostrato sensibilità del canale visivo, sviluppando forti mal di testa quando esposte all'ombra rotante delle pale delle turbine.

3) Disturbo somatosensoriale: una vibrazione anomala del suolo o del pavimento può inviare segnali di movimento e posizione anomali ai centri di equilibrio del cervello attraverso i recettori di stiramento nei muscoli e nelle articolazioni delle gambe. Numerosi soggetti hanno percepito questo tipo di vibrazione, ma non sono certa se abbia innescato il disturbo generale dell'equilibrio. Non sono certa che questo canale sia importante.

4) Disturbo del gravicettore viscerale: comprende il quarto canale da poco scoperto di rilevamento di movimento e posizione, i *gravicettori viscerali* o i recettori di stiramento e pressione negli organi interni del torace e dell'addome. Questo canale di equilibrio è quasi sconosciuto a molti medici, perché all'università ci hanno insegnato che solo tre sensi influiscono sull'equilibrio.

   I gravicettori viscerali si basano sui recettori di stiramento e pressione all'interno e intorno agli organi interni. Questi recettori consentono al cervello di sapere se siamo ad esempio in posizione rovesciata, individuando lo spostamento della massa ematica del corpo dalle gambe al torace. I recettori rilevano che i grandi vasi

> sanguigni nel torace sono allungati o hanno una massa superiore oppure confrontano la pressione del sangue all'interno degli organi o vasi sanguigni posti più in alto o più in basso nel corpo. Si ritiene che questa sia la ragione per cui gli astronauti in orbita intorno alla terra, nella cosiddetta "microgravità", hanno la sensazione di essere rovesciati. I vasi sanguigni delle gambe sono più resistenti e rigidi, poiché in piena gravità terrestre, devono contrastare la tendenza del sangue a raccogliersi alla base (piedi e gambe). Quando manca la forza di gravità che manda il sangue ai piedi, il tono vascolare naturale spinge di nuovo tutto nel torace. In presenza di gravità, ciò accade solo se una persona si trova a testa in giù, ed è così che il cervello interpreta la ridistribuzione del sangue.

La documentazione sull'equilibrio suggerisce che i gravicettori viscerali ricoprano un ruolo fondamentale nel mal d'auto e mal di mare, poiché sono i rilevatori di movimenti insoliti verso l'alto e verso il basso e contraddicono quanto il resto del sistema d'equilibrio sta dicendo. Per esempio, alzarsi e guardar l'orizzonte aiuta a vincere il mal di mare. Così facendo infatti si riportano le informazioni che giungono dagli occhi e dai recettori di movimento nelle gambe in sintonia con i segnali di movimento viscerali e vestibolari. Anche compensare con le gambe I movimenti delle onde che gli organi interni percepiscono aiuta ad evitare il mal di mare.

I gravicettori interni offrono un potenziale collegamento con la sensazione di tremore o pulsazione nel torace e il resto dei sintomi di VVVD, e passano informazioni sulla pressione e sullo stiramento nel torace direttamente al sistema vestibolare. Balaban documenta questi collegamenti neurali (vedi oltre). Un'alternativa, suggerita dal Dott. Owen Black (un neurotologo) è che le variazioni di pressione nel torace possono causare dei cambiamenti nella pressione del liquido intorno al cervello (occorrenza nota), che a sua volta potrebbe provocare un dislivello di pressione (e quindi sintomi vestibolari) nell'orecchio interno di alcune persone affette di questo tipo di problemi.

Il VVVD ci ricorda che il torace è un recettore delle fluttuazioni della pressione dell'aria (descritte sopra alle pp. 33). Ogni forma di suono nell'aria, dalla bassa all'alta frequenza, è composta da stringhe di impulsi di pressione. Quando respiriamo, le vie respiratorie e i polmoni, che riempiono quasi completamente il torace, sono aperte all'aria. La pressione del suono può facilmente entrare nei polmoni e mettere in movimento il loro sistema elastico e mobile con pochissima energia.

Il ruolo più importante dei recettori di stiramento e di pressione negli organi interni e intorno ad essi potrebbe in effetti essere per esempio l'omeostasi fisiologica, il rilevamento della velocità, le dimensioni, la pressione e il flusso del ritmo cardiaco e la respirazione, cioè quello di mantenere il cervello informato sulla situazione. Il rilevamento della pressione nel torace è importante per la regolazione della respirazione, poiché inspirando si crea una pressione negativa nel torace ed espirando si crea una pressione positiva. Il rilevamento della vibrazione può essere importante anche per il monitoraggio del flusso nelle vie respiratorie e vasi sanguigni. L'organismo è particolarmente sensibile a (e facilmente allarmato da) qualsiasi alterazione della pressione necessaria all'inspirazione e all'espirazione. Ritengo che questo sia il motivo per cui numerosi soggetti sentivano di non riuscire a respirare normalmente quando erano esposti alle pulsazioni di pressione dell'aria delle turbine: le pulsazioni innescavano gli stessi recettori della pressione e del flusso come nella respirazione normale, ma al momento sbagliato del ciclo di respirazione o in modo anormale.

Ora che abbiamo visto come le turbine possano provocare disturbi all'equilibrio in persone predisposte, passiamo a discutere come si passa da segnali vestibolari disturbati a quelli che sono considerati i sintomi meno credibili della sindrome: gli attacchi di panico e i problemi intellettivi e mnemonici.

Innanzitutto il sistema di equilibrio del cervello è legato neurologicamente alla paura e all'ansia.

Torniamo ai pesci, cioè ai rudimenti del sistema vestibolare. I pesci con sistemi uditivi semplici, come il teleosteo, percepiscono i movimenti circostanti dell'acqua con i propri organi vestibolari, utilizzando tali informazioni per cercare le prede e per evitare di divenire prede loro stessi. È logico che un sistema dotato di un ruolo fondamentale per la sopravvivenza sia collegato alle connessioni cerebrali che controllano la paura e avvertimento, per le fughe veloci. Ricordiamo anche tutte le storie su animali che percepiscono e fuggono da terremoti, tsunami, vulcani in eruzione, fenditure dei ghiacci, eventi che rimbombano o emettono un rumore e una vibrazione a bassa frequenza, molto prima che gli esseri umani ne diventino consapevoli. Il rilevamento di questo tipo di segnale è anche legato alla risposta della paura: gli animali fuggono.

La Dott.ssa Carey Balaban, un'esperta del cervello, studia le connessioni tra cellule cerebrali e l'equilibrio e i centri cerebrali che controllano l'ansia e la paura, le reazioni autonomiche (quali battito cardiaco accelerato, sudorazione, nausea, ecc.) e l'apprendimento avversivo (la nausea che porta ad evitare qualcosa). I segnali di equilibrio alterati alimentano direttamente paura, ansia e rapide reazioni fisiche, sia autonomiche (reazione interna di lotta o di fuga) che muscolari (rapidi movimenti correttivi del tronco e degli arti). Balaban dimostra che le reti nervose stesse inviano queste comunicazioni al cervello.

Balaban dimostra il concetto con una storia. Immaginate di aver fermato la vostra macchina su una collina (rivolta verso la cima), diciamo, a San Francisco. Con la coda dell'occhio, notate che l'autocarro vicino a voi inizia a muoversi in avanti. Questo vi da immediatamente l'impressione di essere voi a scivolare all'indietro! Panico! Schiacciate immediatamente il pedale del freno! La spavento scompare immediatamente non appena vi rendete conto di non muovervi affatto.

La spiegazione di Balaban sottolinea che l'impressione di non essere stabili nello spazio, di stare quasi per cadere oppure il movimento inaspettato attraggono immediatamente l'attenzione, con denso di allarme e paura. Se la sensazione di movimento inaspettato si protrae per un lungo periodo di tempo, come nel caso delle vertigini, il senso di paura può divenire cronico.

Studi condotti da psichiatri e specialisti che studiano l'equilibrio mostrano come i collegamenti tra l'ansia e i problemi di equilibrio agiscano clinicamente e nella vita reale. Una forma lieve di disordine dell'equilibrio, definita *disturbo di spazio o movimento*, provoca malessere o vertigini in situazioni come nelle corsie dei supermercati, guardare edifici molto alti, chiudere gli occhi sotto la doccia, inclinare all'indietro una sedia, attraversare un tunnel in macchina, salire in ascensore o leggere in macchina. Queste persone mostrano anomalie nel controllo dell'equilibrio. Si tratta generalmente di un problema di equilibrio centrale, vale a dire che il cervello ha delle difficoltà ad integrare tutti i diversi segnali che giungono al sistema di equilibrio e decidere quali di essi ignorare, se non sono coerenti.

*Disturbo di spazio e movimento* è particolarmente diffuso tra persone affette da disturbi emicranici. Lo stesso vale per capogiro, vertigini e nausea provocata dal movimento. Test di equilibrio tendono a risultare anomali negli individui affetti da disturbi emicranici rispetto a altre persone colpite da altri tipi di mal di testa, in particolare se il paziente con emicrania presenta anche capogiri e vertigini. Tra l'altro, problemi di equilibrio in persone affette da disturbi emicranici hanno la loro origine a volte negli organi vestibolari dell'orecchio interno, altre nel cervello.

Problemi di ansia sono inoltre associati ad emicrania, e condividono un percorso comune nei sistemi serotoninici del cervello. Il *disturbo di spazio e movimento* è comune in persone che hanno problemi di ansia.

I test sull'equilibrio dimostrano che i pazienti affetti da ansia mostrano una più elevata sensibilità vestibolare (orecchio interno), rispetto agli individui senza problemi di ansia. Quando si eseguono test su persone a cui sono stati diagnosticati attacchi di panico o agorafobia (paura di lasciare la propria casa), un numero elevato risulta avere delle anomalie della funzione vestibolare, in alcuni studi oltre l'80%. Ciò si riscontra in particolare in persone che presentano episodi di vertigini tra gli attacchi di panico.

In breve, *esiste una solida documentazione clinica e sperimentale a sostegno della connessione biologica tra il disturbo dell'equilibrio e l'ansia, e tra i problemi di equilibrio e gli attacchi di panico*. Per cui è clinicamente logico che *il disturbo del sistema di equilibrio di una persona possa provocare paura, agitazione e panico*, e sintomi fisici, come battito cardiaco accelerato.

Ora prendiamo in considerazione la concentrazione e la memoria. La ricerca attuale dimostra che anche la memoria è condizionata da segnali vestibolari coerenti. Se qualcuno letteralmente non sa dove siano sopra e sotto, in qualsiasi momento, il suo cervello non riesce ad elaborare un gran numero di dati relativi alla posizione nello spazio. Ad esempio:

1) reale posizione nello spazio come

    a) ricordare come arrivare in un certo luogo

    b) riuscire a trovare il modo di assemblare qualcosa oppure

2) posizione nello spazio astratto come

    a) la distanza tra due numeri

    b) la sequenza di avvenimenti nel tempo

    c) la classificazione di oggetti nella memoria

I neurologi hanno recentemente dimostrato che i nervi del sistema vestibolare seguono un percorso bineuronale diretto all'ippocampo, una struttura del cervello fondamentale per la memoria e, in particolare, per l'apprendimento generale e spaziale. Gli individui completamente privi di input dell'orecchio interno al cervello (recisione dei nervi anni prima per la rimozione di un tumore) non sono in grado di eseguire dei compiti riguardanti gli spostamenti e la memoria spaziale, e il loro ippocampo mostra dimensioni ridotte rispetto a quelle normali (al contrario, i tassisti londinesi possiedono un ippocampo di grandissime dimensioni, a seconda degli anni di lavoro e di memorizzazione dei dati su località, scorciatoie e sensi unici).

Gli esami di funzione MRI e PET (vedi sezione abbreviazione) permettono oggi ai ricercatori di individuare quali parti vengano impiegate dagli esseri umani in stato di veglia per eseguire vari compiti, mentre li stanno eseguendo. La stimolazione del sistema vestibolare (equilibrio dell'orecchio interno) mette in funzione varie aree del cervello, ad esempio quelle usate per immaginare lo spazio e quelle riguardanti il pensiero matematico.

Se l'input vestibolare è distorto (ad esempio, se si versa acqua ghiacciata in un orecchio), le persone cadono più spesso in errore nel risolvere compiti spaziali puramente mentali, come ad esempio nell'immaginare un certo oggetto nei particolari o nell'immaginare di farlo ruotare. Queste persone durante il test erano sedute e ferme, con gli occhi chiusi, e pensavano solamente, senza cercare di mantenersi in equilibrio né di capire dove si trovavano nello spazio. Tuttavia, quando da un orecchio interno sono arrivati segnali che indicavano movimento – segnali che contraddicevano tutti gli altri segnali che i loro centri dell'equilibrio stavano ricevendo - hanno ricordato gli oggetti con minore accuratezza e hanno fatto errori, quando cercavano di immaginarli in posizioni diverse.

In altre parole, *i segnali disturbati provenienti dall'orecchio interno alterano sia la memoria spaziale che l'abilità e la precisione del pensiero*. La qualità dell'abilità e della precisione del pensiero si chiama *concentrazione*.

Un cluster di centri del cervello che riceve i segnali dall'orecchio interno (diventano attivi negli studi funzionali di MRI o PET con la stimolazione degli organi vestibolari) si trovano nei lobi parietali del cervello. Se c'è un ictus nell'emisfero destro del cervello e i centri parietali destri sono fuori uso ci possono essere dei risultati molto strani. Questi poveretti, chiamati "eminegletti" (*emi* = "metà" + *negletti* cioè abbandonati da metà del corpo e dello spazio), non sono consapevoli del loro lato sinistro dello spazio, cioè non si rendono conto di avere il braccio sinistro paralizzato o di essere nudi dalla parte sinistra. La stimolazione vestibolare però inverte temporaneamente questo stato e i pazienti percepiscono la loro parte sinistra in modo più normale.

Gli individui "eminegletti" fanno alcuni tipi di errori nella ricerca visiva e in compiti di memoria visiva con risposte divergenti dalla sinistra e preponderanti verso la parte destra delle immagini. La stimolazione vestibolare sinistra corregge o migliora la prestazione in questi esercizi.

Altri studi sugli individui "eminegletti" ci mostrano quali tipi di attività mentali vengono "spazializzati". Ciò significa che richiedono il tipo di pensiero spaziale che avviene nei centri del lobo parietale destro, connesso con il sistema vestibolare. Il pensiero spazializzato include le operazioni matematiche, come ad esempio farsi un'immagine mentale di un righello con i numeri (numeri più bassi a sinistra, numeri più alti a destra) e individuare il punto medio tra due numeri. Comprende anche la capacità di visualizzare il tempo su un orologio e di usare un'ortografia corretta iniziando a scrivere da sinistra e finendo a destra.

Ricerche condotte da importanti studiosi indicano inoltre quanto sia importante il pensiero spaziale. I grandi matematici pensano alla matematica in termini di spazio (è molto efficace perché la rappresentazione neurale dei numeri è spaziale) e i geni della memoria usano metodi che sfruttano concetti di spazio.

In breve, *molte operazioni eseguite con il cervello si basano sul pensiero spaziale o sulla memoria.* Il pensiero spaziale a sua volta necessita un input vestibolare appropriato: abbiamo letteralmente bisogno di sapere dove siano sopra e sotto per capire dove si trovino le cose nello spazio fisico o nel pensiero. La riduzione o la distorsione dei segnali neurali vestibolari sbilanciano il pensiero spaziale, rendendolo meno efficiente e meno accurato.

Ora pensate ai particolari compiti che le persone intervistate nel mio studio non riuscivano più ad eseguire, cioè alle cose che mi hanno spontaneamente detto su sé stessi e sui loro figli, come ad esempio

a) "Non riesco a credere di non essere più in grado di fare una cosa tanta semplice!"

b) "Mio figlio lo sapeva fare ed ora proprio non ci riesce più e si spazientisce ed è frustrato quando lo faccio riprovare."

Le lettere e i numeri qui sotto si riferiscono alla tabella dell'anamnesi dei casi. Ho aggiunto una descrizione in corsivo delle caratteristiche spaziali delle azioni da compiere.[6]

**A1** Ricordarsi che cosa gli serviva quando è arrivato al negozio. M*emoria spaziale dell'immagine della cosa che voleva.*

**B2** Ricordarsi una serie di commissioni e di che cosa prendere in città. M*emoria spaziale degli oggetti e dei luoghi dove acquistarli, calcolo spaziale del percorso più efficiente e dell'ordine in cui acquistarli.*

**C1, D1, G3** Leggere. *Convertire l'input spaziale (parole sulle pagine) in linguaggio e poi in concetti e immagini (anche questi spaziali). C'è anche il controllo vestibolare diretto del movimento degli occhi.*

**C2, G2** Eseguire attività multiple in cucina e in casa. *Avere sia una mappa interna di località che di orari di elementi molteplici. Inserire queste mansioni ed eventi nella mappa, senza dimenticarli quando non sono più visibili.*

**C7** Matematica—abilità perse e fatti matematici dimenticati. *Rappresentazione spaziale dei numeri e delle relazioni dei numeri.*

**E2** Ortografia e scrittura. *Ordinare le lettere nel giusto ordine in modo che appaiano giuste. Convertire la lingua in rappresentazione visiva.*

**F2** Assemblaggio dei mobili. *Essere in grado di convertire istruzioni scritte o diagrammi in una rappresentazione mentale tridimensionale di come assemblare i pezzi*

**F2** Seguire le istruzioni di una semplice ricetta. *Immaginare e ordinare i vari passaggi nella mente, ricavandoli dalle istruzioni scritte.*

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6. See Pierpont (2009) for the Case Histories.

**F2** Seguire la trama di un programma televisivo. *Notare, ricordare e associare gli indizi visivi.*

**F3** Risultati peggiori agli esami nazionali rispetto al passato. *Coloro che riescono a memorizzare in maniera eccezionale si avvalgono di strategie spaziali, come descritto sopra.*

**H3** Lettura, ortografia e matematica. *Tutti questi compiti hanno importanti componenti spaziali.*

**I1** Allestimento e manutenzione professionale dei giardini. *Progettare e sistemare cose nello spazio, ricordando ad esempio dove si è messo un attrezzo; giudicare se qualcosa stia riuscendo bene e come correggerlo, pianificare le fasi dei vari compiti in modo efficiente nel tempo e nello spazio, senza dimenticare le varie fasi.*

**J1** Pagamento delle bollette. *Matematica, memoria degli oggetti e dei servizi acquistati, calcolo mentale delle necessità future.*

Ogni attività problematica mostra un pensiero spaziale pieni di errori e di azioni inefficienti e persone terribilmente frustrate perché non sono più in grado di eseguire compiti per i quali è necessario semplice buon senso comune e che improvvisamente non riescono più eseguire in maniera efficiente (anche il “buon senso” ha un’importante componente di pensiero spaziale). È disturbato anche l’apprendimento scolastico elementare, ad esempio la lettura e certi tipi di abilità mnemoniche e, negli adulti, la capacità di risolvere problemi.

L’interferenza del rumore con la lettura e l’apprendimento dei bambini non è una scoperta recente. La documentazione a disposizione è molto vasta. In breve, il rumore ambientale di un aeroporto o del traffico rallenta l’apprendimento dei bambini. In questi studi sono stati analizzati ampi gruppi di bambini, mediante un controllo attento dei gruppi esposti e non esposti, selezionando quartieri differenti, in aree diverse, in relazione agli aeroporti. I bambini sono stati esposti ad un rumore eccessivo a scuola e a casa.

Ad esempio, in uno studio, una città ha deciso di chiudere un vecchio aeroporto e costruirne uno nuovo, e i ricercatori hanno avuto l’opportunità di seguire nel tempo le capacità di lettura di entrambi i gruppi di bambini. Quelli residenti vicino all’aeroporto che è stato chiuso, hanno mostrato un miglioramento nella lettura, mentre quelli vicini al nuovo aeroporto hanno mostrato un rallentamento dell’apprendimento in corrispondenza dell’inizio del via vai di aerei in decollo e atterraggio.

Uno studio ha preso in considerazione bambini che vivono in un edificio vicino ad un’autostrada molto trafficata. Quelli che vivevano ai piani superiori, più silenziosi, hanno mostrato dei migliori livelli di lettura e migliore abilità a distinguere il suono delle parole.

La capacità di lettura va ben oltre agli effetti di distrazione del rumore ed è connessa a problemi nel processo del linguaggio, ad esempio nella differenziazione dei suoni del linguaggio in un ambiente rumoroso.

È stato inoltre dimostrato che il rumore disturba il pensiero degli adulti anche in altri contesti e con livelli di volume lontanissimi da quelli che rovinano l’udito. In uno studio, gli operai industriali sono stati sottoposti a valutazioni psicologiche mentre erano esposti ad un rumore a banda larga di 50 dBA (come rumore delle macchine o rumore bianco) con o senza componenti a bassa frequenza. I test hanno mostrato che il rumore con componenti a bassa frequenza ha interferito maggiormente con la prestazione, rispetto al rumore privo di basse frequenze, in particolare negli individui che si sono definiti sensibili al rumore. Nessuno dei rumori è stato considerato più fastidioso dell’altro, né i soggetti si sono abituati o sensibilizzati al rumore.

Numerosi studi sul rumore ambientale hanno analizzato gli effetti del rumore ambientale notturno sul sonno, sui livelli dell’ormone dello stress (adrenalina e cortisolo), sulla pressione arteriosa e sui fattori di rischio cardiovascolare. Vi sono associazioni positive significative tra il rumore e ciascuno di questi fattori: l’esposizione al rumore incrementa la produzione dell’ormone dello stress, la pressione arteriosa e il rischio cardiovascolare generale. Livelli elevati dell’ormone dello stress aumentano lo zucchero nel sangue, incrementando la pressione arteriosa, due elementi di rischio cardiovascolare.

Il rumore notturno può disturbare significativamente il sonno, anche se la persona non ricorda di essersi svegliata, poiché la selezione e la registrazione giornaliera dei ricordi avviene durante il sonno (in particolare nella fase REM o sonno con rapido movimento degli occhi). Disturbi del sonno provocati dal rumore, anche senza risveglio cosciente, alterano la memoria e l’apprendimento. La memoria e l’apprendimento vengono inoltre alterati anche da livelli elevati di cortisolo prolungati nel tempo nelle persone in stato di stress cronico e probabilmente riducono il tasso di sopravvivenza di nuove cellule dell’ippocampo.

Nei bambini, l’esposizione al rumore notturno con componenti a bassa frequenza (rumore rimbombante/ vibrante degli autocarri che passano vicino la pareti delle abitazioni) provoca una maggiore produzione dell’ormone dello stress all’inizio della notte rispetto all’esposizione al rumore del traffico senza autocarri.

È interessante notare che i livelli di rumore che disturbano il sonno sono piuttosto bassi. Episodi rumorosi di 32dBA provocano movimenti nel sonno e mostrano un basso livello di risveglio. Episodi rumorosi di 35 dBA causano il risveglio che può essere osservato su un elettroencefalogramma (EEG). Il risveglio cosciente avviene a livelli di rumore di 42 dBA. Per tale motivo, l’OMS (Organizzazione mondiale della sanità) raccomanda 30 dBA come livello accettabile di rumore notturno interno.

Qui non presento analisi del rumore. È certo un aspetto interessante e che chiaramente dovrebbe essere studiato, ma richiede fondi che non ho. Ho tuttavia visto che le descrizioni fino ad ora pubblicate sulle esperienze di persone esposte a documentati rumori a bassa frequenza corrispondono a quanto le persone che ho studiato hanno notato e descritto. (vedi sezione Relazione per Medici)

La Dott.ssa Birgitta Berglund (decano degli studi sul rumore ambientale e principale curatrice delle *Linee guida sul rumore ambientale* 1999 dell’OMS) spiega perché ritiene che molti effetti negativi del rumore ambientale siano generalmente causati dalle componenti di bassa frequenza. Sottolinea inoltre che il rumore a bassa frequenza arriva più lontano senza perdere in potenza, rispetto alle alte frequenze. Attraversa muri e pareti insonorizzati, fa vibrare oggetti, provoca vibrazioni e risonanze nel corpo umano ed è anche connesso al mal di mare (movimento) anche senza vibrazioni. Il rumore a bassa frequenza rende difficile distinguere i suoni a frequenze più elevate, come il suono del linguaggio. Il rumore con componenti a bassa frequenza viene percepito come più assordante e fastidioso del rumore allo stesso livello di dBA senza componenti di bassa frequenza.

È importante ricordare che negli studi sul rumore ambientale il termine “fastidio” viene utilizzato come un eufemismo di una serie di reazioni negative, alcune delle quali gravi. “Oltre al ‘fastidio’ ” dichiara l’OMS, “gli individui… esposti al rumore ambientale … mostrano rabbia, delusione, malumore, scontrosità, sono impacciati, depressi, ansiosi, agitati, distratti o esausti.”

Nella Relazione Per Medici, faccio riferimento a numerosi altri studi minori di esposizione al rumore a bassa frequenza.[7] Ad esempio, i sintomi riportati da giovani sani durante l’esposizione di soli 2–3 minuti al rumore di bassa frequenza con ampiezza elevata negli impianti di prova della NASA durante gli anni sessanta hanno rilevato sintomi di affaticamento, minore efficienza nell’esecuzione dei compiti, fastidio all’orecchio, vibrazioni nel torace e senso di soffocamento in gola. Tutti questi sintomi sono stati riportati anche dalle persone che hanno preso parte al mio studio.

Infatti, la relazione su un caso tedesco del 1996 può quasi certamente essere attribuito alla sindrome da turbina eolica, poiché la fonte del rumore a bassa frequenza (anzi infrasuono, inferiore a 10 Hz) non è stata mai identificata. Si tratta di un caso particolarmente interessante. I sintomi riportati da una coppia e l’intensità del rumore inferiore a 10 Hz hanno avuto variazioni a seconda del vento e delle condizioni meteorologiche, e sono peggiorati durante l’inverno. I sintomi erano:

a) disturbo del sonno

b) mal di testa

c) pressione nell’orecchio

d) malessere in generale

e) minore abilità/ efficienza nell’esecuzione dei compiti

f) sintomi nel torace descritti come affanno e sensazione di formicolio/ brulichio.

I sintomi si verificavano quando il livello di pressione del suono a 1 Hz era di 65 dB, ampiamente sotto al livello di udibilità delle due persone, misurata in un laboratorio acustico. Le frequenze responsabili dei sintomi, tutte inferiori a 10 Hz, avevano livelli di pressione sonora inferiori a 80 dB.

Sappiamo ora in base alle misurazioni di un fisico olandese eseguite molti anni fa e alle valutazioni effettuate da un ingegnere di controllo del suono statunitense che i livelli sonori nei pressi delle turbine rientrano facilmente in questi valori.

Il suddetto caso tedesco del 1996 e un’altra serie di casi riportata da ingegneri di controllo del suono tedeschi (vedere la Relazione Per I Clinici, pp. 106–8), sottolineano entrambi *il modo*

7. Pierpont (2009).

*in cui i sintomi e il grado di fastidio percepito dagli individui aumentino nel tempo dopo un trasloco in case o appartamenti con rumore a bassa frequenza*.[8] Non si sono abituati al rumore, ma, al contrario, col tempo sono diventati più sensibili. All'inizio la cosa non sembrava grave, ma col tempo è gradatamente peggiorata.

I soggetti del mio studio hanno riportato i medesimi episodi, e hanno confrontato il rumore delle turbine con altri tipi di rumore, come il traffico, al quale si sono abituati facilmente. Molti hanno dichiarato che il rumore delle turbine eoliche non sembrava essere fastidioso per le persone che non vivevano nell'area,[9] tuttavia molti hanno menzionato il disturbo riportato dai visitatori che avevano pernottato solo una notte. Tutte le famiglie che si erano trasferite lontano dalle loro abitazioni esposte alle turbine, hanno scelto città e paesi con maggiore rumore del traffico, ma senza la possibilità di edificazione di turbine eoliche nelle vicinanze.

Di conseguenza i disinvolti commenti che dicono "vi abituerete al rumore delle turbine eoliche" sono contraddetti sia dalle persone che trovano difficile viverci vicino che dall'evidenza clinica.

Entrambi i casi di studio tedeschi si sono concentrati sulla capacità del rumore a bassa frequenza (lunghezze d'onda lunghe) di attraversare le pareti e riverberare o innescare una risonanza nelle stanze. Gli autori di questa serie di casi di studio hanno misurato la differenza di intensità del rumore a bassa frequenza vicino e lontano dalle pareti, individuando nodi di intensità più elevata lontano dalle pareti, simili a un'onda stazionaria in una corrente in movimento.

Due partecipanti al mio studio, il sig. e la sig.ra G (G1 e G2) hanno entrambi identificato il punto di una stanza che provocava loro i sintomi, una sensazione di vibrazione interna per la sig.ra G e un principio di senso di nausea per suo marito. Tuttavia non sentivano alcuna

8. Pierpont (2009).

9. Un caso interessante è stato presentato dinanzi al Tribunale dei Diritti Umani dell'Unione Europea lo scorso 26 febbraio 2008, quello di Lars e Astrid Fägerskiöld contro la Svezia (Richiesta n.: 00037664/04). I querelanti hanno citato l'articolo 8 della convezione e l'articolo 1 del protocollo n.1 della convenzione. Di seguito alcuni estratti dalla documentazione del tribunale.

"Secondo i richiedenti, la turbina eolica emette un rumore pulsante costante e talvolta con effetti luminosi, che ritengono *particolarmente fastidiosi e intrusivi*. Per tali motivi e poiché credono che la turbina eolica sia stata eretta troppo vicino alla loro proprietà e senza essere stati consultati in precedenza, hanno inoltrato una lettera di reclamo alla municipalità" (enfasi aggiunta).

"I richiedenti si sono appellati al tribunale amministrativo (länsrätten) della contea di Östergötland, mantenendo la propria accusa. In particolare, *hanno enfatizzato che la turbina eolica è un fastidio particolarmente grave* e che il comitato ambientale ha effettuato un'impropria valutazione della questione, nonché numerosi errori ufficiali nella gestione del caso. Inoltre, dichiarano che la municipalità ha rifiutato di effettuare un'indagine indipendente sul rumore, nonostante la richiesta provenisse da diverse parti in questione" (enfasi aggiunta).

"Il 14 aprile 1999, dopo aver visitato la proprietà dei richiedenti, il comitato amministrativo della contea ha respinto l'appello … *Dalla visita alla proprietà dei richiedenti è stato rilevato che la turbina eolica creava un certo effetto sonoro, ammissibile come fastidioso, ma non serio abbastanza da smantellare la turbina.* In tale rispetto, è stato rilevato che i livelli di rumore non raggiungono il livello massimo raccomandato di 40 dB" (enfasi aggiunta).

"Il 14 luglio 2000, dopo aver visitato la proprietà dei richiedenti e tenuta un'udienza, il tribunale amministrativo della contea ha respinto l'appello, ritenendo la decisione del comitato ambientale conforme alla legge e *sebbene fosse stato possibile osservare alcuni effetti sonori della turbina eolica presso la proprietà dei richiedenti, il disturbo era da considerarsi tollerabile*" (enfasi aggiunta).

Il tribunale ha archiviato il caso.

vibrazione toccando la parete o i mobili con le mani. Ritengo che si trattasse di uno dei punti in cui le onde (pressione dell'aria) sonore a bassa frequenza si sovrapponevano in modo tale da rimbalzare nella stanza e creare un punto stabile o un'onda stazionaria di intensità maggiore.

Durante uno studio, i ricercatori svedesi hanno verificato, in una ricerca condotta su centinaia di abitazioni, che la quantità di rumore necessario a causare un fastidio grave è molto bassa nel caso di una turbina eolica rispetto a quella del traffico di automobili, aeroplani o treni (vedere pp. 112–13 nella Relazione Per Medici).[10] La "quantità di rumore" è stata modellata o calcolata (piuttosto che misurata) in base alla distanza e alla potenza delle turbine. Il rumore è stato definito in dBA (senza prendere in considerazione le componenti a bassa frequenza, anche se presenti), la cui media è stata effettuata nel tempo.

I risultati hanno dimostrato che il 15% degli individui era più disturbato da 38 dBA delle turbine eoliche che da 57 dBA del traffico aereo, da 63 dBA del traffico automobilistico e da 70 dBA del traffico ferroviario. Quando il rumore della turbina eolica raggiungeva 41 dBA, il 35% degli individui è risultato molto infastidito. Il sedici percento ha indicato un disturbo del sonno in presenza di 35 dBA di rumore proveniente da una turbina all'esterno.

Quando questi ricercatori hanno intervistato alcuni dei partecipanti al sondaggio per ottenere delle informazioni più dettagliate, hanno riscontrato gli stessi tipi di problemi da me incontrati in questo studio. Tra l'altro, appunto il fatto che alcune persone si siano trasferite altrove a causa del rumore o che altri abbiano ristrutturato la propria abitazione per cercare di eliminare il rumore. Alcuni hanno riportato di sentirsi "invasi" o "violati" dal rumore della turbina, di essere sensibili sia al movimento delle pale che al rumore e di non essere in grado di riposare e sentirsi rilassati in casa.

Da questo si capisce che, a differenza di altri tipi di rumore, nel caso di turbine eoliche *gli standard comunemente ammessi di 45–55 dBA misurabili al di fuori di case di abitazione non sono accettabili e creano problemi*. Il rumore delle turbine eoliche è diverso e più problematico (forse perché la bassa frequenza viene esclusa dalle misurazioni in dBA), quindi gli stessi standard numerici non sono applicabili.

Nel 2007, Pedersen ha collaborato con van den Berg, un fisico olandese, ad uno studio sul fastidio provocato dalle turbine eoliche, questa volta nei Paesi Bassi. Hanno ottenuto gli stessi risultati sul disturbo provocato dal rumore delle turbine eoliche (modellato) rispetto ad altri tipi di rumore. Nei risultati dello studio olandese, è stato introdotto con discrezione un nuovo elemento. Nello studio olandese i proprietari delle turbine vivevano nei pressi delle turbine, e *ne ottenevano benefici economici, essendo inoltre in grado di spegnere le turbine quando loro o i vicini erano disturbati dal rumore*, una differenza fondamentale rispetto agli altri paesi. Se le turbine si fossero potuto spegnere in seguito alle lamentele sul rumore dei cittadini di Canada, Stati Uniti, Regno Unito, Irlanda o Italia, non mi sarei trovata a scrivere questa relazione.

Van den Berg e Pedersen affermano di aver studiato anche la salute in relazione al rumore delle turbine eoliche, ma il loro tentativo era talmente impreciso da essere privo di valore. I risultati presentati lo dimostrano chiaramente. Il sondaggio postale da essi elaborato conteneva solo due domande sulla salute (le domande sul sonno erano separate). Una

10. Pierpont (2009).

indagava su tutte le malattie croniche presenti e passate in una domanda sola. Le risposte dimostrano la mancata obiettività del sondaggio (per il modo in cui erano stati selezionati i partecipanti oppure per come erano state formulate le domande) e non presentano affatto un quadro chiaro del numero di persone affette da malattie croniche nella popolazione studiata. Questo è evidente, perché il numero delle risposte su almeno due delle condizioni croniche ricercate (cioè emicrania e tinnito), è risultato molto ridotto rispetto a quanto risulta da indagini sulla popolazione comune, per le quali è stato stabilito con numerosi e ben bilanciati studi.

Ciononostante gli autori hanno usato i propri dati come validi al fine di verificare l'ipotesi, ugualmente poco ponderata, che gli effetti sulla salute, se presenti, dovrebbero manifestarsi con più patologie croniche nel caso di persone residenti vicino alle turbine piuttosto che in quelle che vivono ad una distanza di 2,1 km. Hanno creduto di poter provare (o controbattere) quest'ipotesi con i vaghi risultati di un sondaggio che non è stato in grado di rilevare neanche i disturbi emicranici che sono presenti al 20% nella popolazione reale. In veste di specialista (ritengo che né van den Berg, né Pedersen lo siano) posso categoricamente dire che per i tipi di studio in grado di dimostrare l'effetto del rumore sulle malattie croniche c'è un'ampia quantità di dati su una vasta popolazione (o campioni di studio) e che le informazioni sulle patologie croniche (generalmente malattie cardiovascolari o produzione dell'ormone dello stress nello studio sul rumore e sugli effetti sulla salute) sono state accuratamente definite sia nei soggetti che nei controlli. Non è possibile affrontare l'argomento con i dati forniti da van den Berg e Pedersen. Il confronto tra l'ipotesi e i dati raccolti con questo metodo non è possibile. Sotto un punto di vista clinico, il loro studio non ha nessun valore.

Per dirlo in modo ancora più chiaro: *Non si può partire da un'ipotesi non plausibile o un gruppo di dati non obiettivo e ottenere risultati che abbiano un senso*. Van den Berg e Pedersen non sembrano rendersi conto che si tratta di salute. Hanno prodotto un mucchio di numeri, ma non si rendono conto delle limitazioni del loro studio sui dati relativi alla salute e in quale modo questi dati non obiettivi limitino le conclusioni che si possono trarre dalla loro ricerca.

La seconda delle domande riguardanti lo stato di salute da loro poste è una lista di possibili "sintomi correnti", uno strano miscuglio di sintomi fisici e psicologici con pochissime parole che li descrivano con un linguaggio semplice e comune. La domanda non ottiene praticamente alcuna informazione utile. Questa domanda è citata una sola volta nella loro relazione, a proposito del fatto che le persone intervistate che non avevano ottenuto benefici economici dalle turbine riportavano più sintomi di quelle che avevano avuto benefici economici, e commentavano la differenza supponendo che la spiegazione fosse la differenza sistematica di età tra il gruppo che aveva ottenuto benefici e quelli che non li avevano ottenuti (che erano più anziani).

Sebbene sia chiaro che nella loro relazione le indagini sugli effetti sulla salute siano stati carenti e insufficienti, van den Berg e Pedersen traggono conclusioni che solitamente vengono interpretate come se asserissero che le turbine non hanno effetti negativi sulla salute. Basta tuttavia leggere quanto dichiarano nel loro sommario: "Non c'è stata alcuna indicazione che le turbine eoliche abbiano avuto un effetto sulla salute dei rispondenti, ad eccezione dell'interruzione del sonno" (p. ii). Sebbene gli autori tentino di minimizzare il fatto, l'interruzione del sonno ha enormi conseguenze per la salute. Oltretutto, a parte la faccenda del sonno, i due sono in ogni caso in errore, visto che il loro studio non è riuscito ad individuare altri effetti sulla salute.

In conclusione, van den Berg e Pedersen avrebbero potuto cogliere in modo migliore i risultati (limitati) sulla salute del sondaggio, se avessero scritto “Il disturbo o l’interruzione del sonno, un effetto di profonda importanza sulla salute, è correlato ai livelli di rumore delle turbine. Sfortunatamente, il sondaggio non ha potuto affrontare altre questioni relative alla salute a causa della mancanza di obiettività nel metodo di raccolta dei dati. Un dato importante emerso dallo studio è la possibile mancanza di obiettività dei partecipanti al sondaggio che hanno avuto benefici economici, ma è ugualmente possibile che i proprietari delle turbine abbiano l’abitudine di spegnere le turbine nei momenti critici, evitando così il fastidio e il disturbo del sonno”.

## Raccomandazioni

George Kamperman e Rick James, due ingegneri statunitensi, liberi professionisti nel campo del controllo del rumore, con decenni di esperienza sul rumore industriale e sugli effetti sulle comunità, raccomandano uno standard che si basa sul rumore ambientale di fondo più silenzioso e usano misurazioni C e A in modo da poter controllare i componenti a bassa frequenza. Le raccomandazioni specifiche, per la corretta esecuzione della misurazione del rumore e delle ordinanze locali sulle procedure sono state presentate nel 2008 in occasione della conferenza annuale dell’Institute of Noise Control Engineering (USA) e sono accessibili sul sito web sulla sindrome da turbina eolica www.windturbinesyndrome.com/?p=925. Un importante risultato del metodo di Kamperman e James è che se le turbine aumentano di misura le distanze e le aree da mantenere tra loro e le abitazioni devono essere maggiori.

La risposta è semplice: *mantenere le turbine eoliche ad almeno 2 km di distanza in pianura e 3,2 km in montagna. Queste sono le distanze minime. I metodi di Kamperman e James raccomandano probabilmente delle aree di salvaguardia maggiori, in particolare nelle aree rurali che normalmente sono molto silenziose.* Secondo punto: tutte le regolamentazioni sulle turbine dovrebbero rendere chi le produce responsabile per il rilevamento a pieno prezzo (cioè prima dell’installazione delle turbine) delle abitazioni di tutte le famiglie, le cui vita è stata rovinata dall'installazione delle turbine. I produttori di turbine dovrebbero inoltre essere costretti a seguire regole obiettive sulla salute, in modo da evitare le terribili perdite economiche che risultano dall’abbandono delle case.

**Tabella 1: Sintomi del disturbo vestibolare con vibrazioni viscerali (VVVD)**

(Nota: nelle Tabelle, il codice alfanumerico indica la tabella della Documentazione Individuale di Pierpont 2009).

*Tremito, vibrazione o pulsazione interna*. Undici soggetti adulti hanno descritto queste sensazioni come fastidiose, insolite e difficili da spiegare:

- J1 (età 49 anni), un medico, ha descritto “il tremito interno” come parte della “sensazione di nervosismo” che lo assale quando le turbine giravano velocemente.
- I2 (età 52 anni) ha definito il rumore in casa come una “pulsazione bassa, quasi una vibrazione”, che non veniva eliminata neanche dai tappi per le orecchie. Al risveglio notturno, la donna ha notato una sensazione di “punture di spillo” nel torace, simile ad un “formicolio” e una stretta al petto causata dal rumore. “Condiziona il mio corpo,

questo tipo di sensazione avviene quando sono agitata o scossa, provocandomi pressione o fischio nelle orecchie". "La percezione che qualcuno abbia invaso non solo la mia salute e il mio territorio, ma anche il mio corpo".

- H2 (età 57 anni) ha descritto una pulsazione che disturbava il sonno a causa del rumore "innaturale" delle turbine.
- G1 (età 35 anni) ha descritto una sensazione di disorientamento e una "particolare anomalia" in alcune parti della casa, in cui poteva "percepire un rimbombo". Se non si spostava in fretta da questi punti della casa, si creava una sensazione di nausea. Ha definito il rumore "talvolta molto invasivo. Il rumore del treno è di tipo diverso e non è invasivo".
- G2 (età 32 anni) ha avvertito disorientamento, "stordimento", con vertigini e nausea nel giardino e in aree particolari della casa in cui poteva percepire la vibrazione. Sentiva il suo corpo vibrare "all'interno" ma appoggiando le mani su pareti, finestre o oggetti, questi non sembravano vibrare.
- F2 (età 51 anni) ha descritto una sensazione fisica simile ad "un concerto di heavy rock", specificando che il "ronzio era nauseante".
- E2 (età 56 anni), stando supina ha percepito un "ticchettio" o "pulsazione" nel torace al ritmo del sibilo delle pale della turbina, e lo ha interpretato come se "il suo cuore si fosse sincronizzato al rumore delle pale". Non ci sono però informazioni, come la contemporanea misurazione delle pulsazioni prese al polso, che permettono di stabilire se sia vero o no oppure se non possa aver sentito un tipo diverso di pulsazione. È riuscita a fermare queste sensazioni alzandosi e girando per casa, ma una volta sdraiata di nuovo, sono ricominciate.
- D1 (età 64 anni) percepiva le pulsazioni sdraiato nel letto. Inoltre, "quando le turbine si spostano in una posizione specifica (verso di me), divento davvero nervoso, come se dei tremori mi attraversassero il corpo…è come una vibrazione che proviene dall'esterno … tutto il corpo lo sente, come se ci fosse qualcosa che vibra dentro di me, o come stando seduto su una poltrona vibrante, senza che il mio corpo si muova". Ciò si verifica di giorno o di notte, ma non quando le turbine sono rivolte "di lato".
- C1 (età 45 anni) ha percepito le pulsazioni nel petto che lo hanno portato a trattenere il fiato e ha tentato di resistere alla sensazione nel petto evitando di respirare "naturalmente". Le pulsazioni nel torace hanno interrotto il suo sonno e gli hanno tolto la capacità di leggere. Inoltre, ha descritto una sensazione di "energia proveniente dall'interno del mio corpo… come essere cotto vivo in un forno a microonde".
- B2 (età 53 anni) ha descritto a volte un "affanno" respiratorio, come se al momento di addormentarmi il mio respiro volesse recuperare qualcosa".
- B1 (età 55 anni) ha avuto due episodi di pesantezza al petto mentre era sdraiato, che sono poi scomparsi non appena si è alzato. Inoltre, ha percepito una qualità invasiva del rumore nella testa e nelle orecchie: "Quella roba [rumore delle turbine] non ti esce dalla testa, vi entra e vi rimane, è terribile".

*Agitazione*, *ansia*, *allarme*, *irritabilità*, *nausea*, *tachicardia* e *disturbo del sonno* vengono associati alla vibrazione o alla pulsazione interna:

- La sensazione di "nervosismo" di J1 (età 49 anni) comprendeva "forte ansia", irritabilità e "l'impressione di non essere una persona piacevole con cui stare in compagnia". Ha interrotto le attività all'aperto e con la famiglia per rintanarsi in casa in isolamento. Quando le pale girano veloci e sente un certo tipo di rumore, tornando a casa dal lavoro, ha un senso di nausea e perde l'appetito. Si sveglia con una sensazione di "nervosismo" e tachicardia e talvolta ha bisogno di scendere a dormire su una branda in cantina, a circa 13 gradi centigradi (l'unico luogo in cui non si percepiscono le turbine) per riuscire ad addormentarsi. Quando è in stato di "agitazione" sente il bisogno di respirare profondamente o di sospirare.

- I2 (età 52 anni) descrive episodi di "nausea" e perdita dell'appetito, "tremore delle braccia, delle gambe, delle dita", "forte agitazione mentale e fisica" e pianto frequente inaspettato. Durante le notti rumorose, si è svegliata dopo quattro ore di sonno e ha pianto per il resto della notte. "Quando mi sveglio sento come una sensazione di pressione e una stretta al petto, con conseguente panico e paura". Si tratta di un "risveglio allarmante, una sensazione che sia accaduto qualcosa e non so cosa". Una volta si è svegliata credendo che ci fosse stata una scossa di terremoto (erroneamente) e due volte con la tachicardia, una "sensazione che il cuore stia battendo molto velocemente e rumorosamente. Riuscivo a percepire il flusso sanguigno". La sensazione di panico le impedisce di tornare a dormire.
- H2 (età 57 anni) si è svegliata 5–6 volte ogni notte con una sensazione di paura e impulso di controllare la casa. Lo descrive come un modo "molto disturbato di svegliarsi, con un sobbalzo, come se qualcuno avesse appena fracassato un vetro della finestra per entrare in casa. "Pur sapendo di che cosa si tratta si sente il bisogno di controllare, aprire la porta d'ingresso, è orribile". Le riesce difficile tornare ad addormentarsi e si descrive come irritabile ed arrabbiata, grida di più contro gli altri membri della famiglia.
- G1 (età 35 anni) ha definito "stressante" il rumore fuori della propria abitazione e il rumore che lo sveglia la notte.
- G2 (età 32 anni) durante l'esposizione era irritabile, arrabbiata e preoccupata per il futuro dei propri figli. Si svegliava spesso nel mezzo della notte, perché si svegliavano i figli, ascoltava le loro paure, senza mai parlare delle proprie.
- F2 (età 51 anni) ha descritto una "sensazione di inquietudine costante". Di notte si svegliava con un sobbalzo e battito cardiaco accelerato, una sensazione di paura e si sentiva irresistibilmente spinta a controllare la casa. La sensazione di allarme le impediva di riaddormentasi.
- E2 (età 56 anni) non ha espresso ansia o paura, ma si svegliava continuamente durante la notte e non riusciva ad addormentarsi quando le turbine erano rivolte verso la sua abitazione.
- D1 (età 64 anni) ha descritto il modo in cui si doveva "calmare" dal "tremito". Se fuori di casa, "devo rientrare, sedermi e cercare di calmarmi. Dopo un episodio simile, sono molto stanco". L'umore è peggiorato e sente rabbia, frustrazione e aggressività. Talvolta, il "tremore" è stato accompagnato da tachicardia: "Sembra che il cuore impazzisca e percepisco questi tremori su tutto il corpo". Il signor D respira affannosamente o soffre di iperventilazione, con tremori e tachicardia, e deve consciamente rallentare la respirazione per calmarsi.
- C1 (età 45 anni) non era in grado di riposare in casa, dove il corpo è "sempre in stato di difesa". Per riposare si doveva allontanare in macchina.
- B2 (età 53 anni) si sentiva "in agitazione e tumulto" e quando i sintomi peggioravano si doveva ripetutamente allontanare dalla sua casa e dalla proprie mansioni per sentirsi meglio.
- B1 (età 55 anni) ha descritto stress, "molto, quasi al massimo della tolleranza, il rumore e l'attività frenetica, mi hanno sfinito". Il medico gli ha prescritto degli

ansiolitici e ha trascorso più tempo sulla costa a pescare con la propria barca per attenuare i sintomi.

Il tremito, la vibrazione o la pulsazione interni, associati ad agitazione, ansia, allarme, irritabilità, tachicardia, nausea e disturbo del sonno costituiscono il *disturbo vestibolare con vibrazioni viscerali* (VVVD).

**Tabella 2: resoconti dei sintomi legati alla concentrazione e alla memoria**

Le difficoltà mentali o mnemoniche sono talvolta sconcertanti se si pensa alla professione o al comportamento normale dei soggetti:

- A1 (età 32 anni), un pescatore di professione, dotato di barca propria, che prima dell'esposizione alle turbine aveva avuto qualche difficoltà isolata a ricordare nomi e facce, non è stato più in grado di ricordare di cosa avesse bisogno entrando in un negozio, se non lo scriveva su un bigliettino.
- B2 (età 53 anni), casalinga, si confondeva, quando andava in città a sbrigare commissioni, se non scriveva quello che avrebbe dovuto fare e doveva tornare a casa a prendere la lista.. Quando l'ho intervistata sei settimane dopo essere traslocata altrove, ha dichiarato di essere migliorata e di essere capace di sbrigare tre cose di fila senza aiutarsi con una lista.
- C1 (età 45 anni) ha dovuto smettere di leggere, perché non riusciva a concentrarsi quando percepiva le pulsazioni.
- C2 (età 42 anni), una donna molto organizzata, madre di sei bambini, sempre pronta "un mese prima di qualsiasi compleanno" prima dell'esposizione, è diventata disorganizzata e ha avuto difficoltà ad eseguire diverse azioni combinate, anche in cucina, tanto che ripetutamente ha lasciato bollire ed evaporare completamente l'acqua sul fornello. Ha dichiarato: "Credevo di essere sull'orlo della pazzia".
- D1 (età 64 anni), un disabile. ingegnere industriale in pensione, ha notato un rallentamento progressivo nel richiamare fatti alla memoria e una maggiore difficoltà a ricordare quello che aveva letto.
- E2 (età 56 anni), un insegnante in pensione, molto attiva nelle iniziative sociali, non riusciva a usare una corretta ortografia, scrivere e-mail o mantenere il filo logico della conversazione al telefono quando le pale della turbina erano rivolte verso la sua abitazione, ma riusciva a farle quando le pale erano rivolte altrove.
- F2 (età 51 anni), un'infermiera con specializzazione in pediatria, ostetrica e con diploma in amministrazione sanitaria, si era accorta di non riuscire a seguire ricette, le trame di trasmissioni televisive o le istruzioni di montaggio di mobili.
- G2 (età 32 anni), una donna molto organizzata, madre di quattro bambini, ha iniziato a dimenticare le cose e doveva scrivere tutto su un bigliettino, poiché non riusciva a concentrarsi e a organizzarsi. Ha perfino dimenticato un appuntamento per un test dell'udito di suo figlio. Non aveva mostrato problemi di memoria o concentrazione durante un precedente periodo di depressione all'età di 18 anni. Ha detto della sua esperienza "questa volta era diversa".
- I1 (età 59 anni), un giardiniere professionista non è stato più in grado di concentrarsi sulla propria attività di giardiniere, quando le turbine erano rumorose, e ha dichiarato "dopo mezz'ora dovevo andare via, allontanarmi, chiudere la porta".

- J1 (età 49 anni), un medico, ha notato dei gravi problemi di concentrazione quando si sedeva per pagare dei conti in un piccolo ufficio con una finestra rivolta verso le turbine.

Un calo nel rendimento scolastico, in rapporto al periodo precedente all'esposizione - o un deciso miglioramento dopo essersi allontanati dalle turbine - è stato notato su 7 dei 10 bambini e adolescenti (tra 5–17 anni) che frequentavano una scuola. Ad esempio:

- F3 (età 17 anni), una studentessa diligente che non si preoccupava affatto per le turbine ed era convinta che i genitori stessero esagerando con le loro preoccupazioni, ha peggiorato all'improvviso l'esito degli esami nazionali rispetto all'anno precedente, con sorpresa della scuola, della famiglia e di se stessa. A questo punto ha iniziato anche lei ad andare con i propri genitori a dormire in una pensione.
- C7 (età 9 anni), la cui prestazione scolastica era soddisfacente senza alcun bisogno di sostegno esterno prima dell'esposizione, ha ricevuto insufficienze nelle interrogazioni, ha perduto le sue capacità e ha dimenticato le nozioni di matematica che in precedenza padroneggiava. Non è stato più in grado di mantenere il filo logico facendo i compiti per casa. Perdeva il filo e non sapeva più dove era arrivato se si distraeva nel risolvere un problema.
- G3 (età 6 anni), definito un bambino estremamente concentrato e avanzato nella lettura (prima dell'esposizione), non ha voluto più leggere durante l'esposizione. Dopo essersi allontanato per due mesi dalle turbine si metteva a sedere di sua spontanea volontà e leggeva "un libro piuttosto grosso per la sua età" anche per un'ora intera.
- Sua sorella, G4 (età 5 anni), prima dell'esposizione aveva mostrato di avere tempi di concentrazione ridotti. Si supponeva che la perdita dell'udito dovuto a una grave otite media bilaterale cronica interferisse con la prestazione scolastica e nel periodo di esposizione faceva spesso capricci per fare i compiti. Due mesi dopo la fine dell'esposizione, sebbene non ci fossero stati dei cambiamenti nella sua patologia (era in lista di attesa per ricevere tubi di equalizzazione della pressione), ha mostrato maggiore pazienza e ha lavorato più a lungo ai suoi compiti. Sua madre ha notato un "eccezionale miglioramento scolastico".
- H3 (età 8 anni) possedeva una memoria eccellente ed era bravo nella lettura, nell'ortografia e in matematica prima dell'esposizione. Nel corso dell'esposizione era riluttante a fare i compiti e l'insegnante gli ha detto che non si concentrava e che avrebbe dovuto andare a letto prima.

**Tabella 3: tempo necessario per riprendersi dai problemi di memoria e concentrazione**

I problemi di concentrazione e di memoria legati alle turbine sono stati risolti in tempi diversi rispetto ai problemi del sonno. I problemi del sonno sono scomparsi immediatamente, eccetto quando associati a depressione persistente (due soggetti). I problemi di concentrazione e memoria hanno impiegato generalmente più tempo a migliorare, anche in assenza di depressione.

- A1 (età 32 anni) ha classificato la propria memoria all'85% allo stato normale, al 2% durante l'esposizione e al 10% sei settimane dopo il trasloco in una nuova abitazione.
- B1 e B2 (età 55 e 53 anni) hanno dichiarato di aver notato un miglioramento nella propria memoria sei settimane dopo il trasloco.

- C1 (ora 47 anni di età), in costante stato depressivo ed con esposizione continuativa a causa dei lavori domestici, ha notato quanto inefficiente fosse ancora la propria memoria 25 mesi dopo aver traslocato altrove.
- C2 (ora 44 anni di età) ha notato un miglioramento della memoria e della concentrazione 18 mesi dopo aver traslocato, nonostante fosse esposta allo stress di una condizione abitativa sovraffollata. Suo figlio, anch'egli affetto (ora 11 anni di età) non aveva ancora completamente recuperato la sua prestazione scolastica.
- E2 (età 52 anni) si è ripresa immediatamente. Aveva problemi durante l'esposizione solamente quando le turbine erano rivolte verso una particolare direzione.
- F1 e F2 (età 42 e 51 anni) si erano spostati altrove, ma lavoravano ancora presso la loro fattoria e abitazione nei pressi delle turbine. Tre mesi dopo essersi trasferiti, hanno notato un miglioramento nel livello di concentrazione, ma non era ancora tornato allo stato normale. Il signor F affetto da depressione costante non ha notato alcun recupero della memoria.
- G2 (età 32 anni) ha classificato la propria memoria come 10/10 in condizioni normali, 2/10 durante l'esposizione e 5/10 due mesi dopo aver traslocato altrove, nel momento in cui la sua depressione era completamente svanita. I figli della signora G, rispettivamente di 5 e 6 anni, hanno dimostrato un marcato miglioramento della concentrazione nei due mesi successivi al trasloco.

Solo tre soggetti hanno mostrato una netta depressione durante o dopo l'esposizione. G2 (età 32 anni) era caduta in depressione nel periodo della prima intervista (durante l'esposizione), ha però sottolineato la differenza delle proprie funzioni cognitive tra l'attuale esperienza e il primo episodio di depressione all'età di 18 anni, quando non aveva riportato alcun problema di memoria o concentrazione. Due altri soggetti, C1 (età 45 anni) e F1 (età 42 anni) sono caduti in depressione dopo aver abbandonato le proprie abitazioni, e continuavano inoltre ad avere problemi mnemonici. Entrambi erano ancora soggetti ad esposizione.

# Pareri dei referees su Pierpont 2009, Capitolo 2, Relazione Per Medici

La relazione della Dott.ssa Pierpont merita di essere pubblicata. Sebbene il numero dei casi non sia vasto, l'attenta documentazione dei gravi problemi fisici, neurologici ed emotivi provocati dalla residenza nei pressi delle turbine eoliche deve essere portata all'attenzione dei medici che, come me, non ne erano a conoscenza fino ad oggi.

Mediante un questionario/ intervista abilmente redatto, l'autrice è stata in grado di ottenere dei dati che dimostrano la correlazione dei sintomi provocati dalle turbine eoliche, il miglioramento/la guarigione dei sintomi quando gli intervistati si sono allontanati e la ricomparsa degli stessi sintomi al ritorno alle loro case nei pressi delle turbine.

In seguito alle pressioni esercitate sui governi per l'implementazione di una politica "verde", per eliminare le risorse elettriche alimentate a carbone, l'Agenzia americana per la protezione dell'ambiente, in collaborazione con la Dott.ssa Pierpont e tenendo pesente la presente relazione, dovrebbero ampliare questa ricerca e stabilire le linee guida necessarie alla creazione di "fattorie eoliche" e alla protezione dei residenti confinanti.

JEROME S. HALLER, MD, Professore di neurologia e pediatria (in pensione dal 2008), presso Albany Medical College, Albany, New York. Dr. Haller è un membro dell'American Academy of Pediatrics, dell'American Academy of Neurology (Child Neurology Section) e della Child Neurology Society.

10 giugno 2008

Lo studio della Dott.ssa Pierpont affronta un aspetto ancora poco documentato delle patologie provocate dal rumore, in maniera dettagliata nella documentazione dei casi, multisistemica nell'approccio e nelle descrizioni, e con una accurata ed informativa bibliografia.

Lo studio offre un fondamento scientifico per il riconoscimento di complessi di sintomi, generalmente ignorati e difficili da comprendere per la grande maggioranza dei medici che, nella pratica quotidiana, devono essere in grado di identificare anomalie per formulare una diagnosi. Questo approccio al percorso diagnostico e cognitivo è affascinante e ritengo che possa stimolare l'interesse di un gran numero di medici, capaci di considerare il paziente una persona e non una macchina. In tale modo verranno incoraggiati ad ascoltare attentamente i pazienti ed a vederli nell'ambiente e non solo nel laboratorio.

Lo studio della Dott.ssa Pierpont è particolarmente rilevante nell'ambito dell'attuale crisi energetica (e a causa del ruolo che ricoprono le tecnologie che mutano l'ambiente), ed è anche piacevole da leggere, con un ottima bibliografia e ricco di informazioni. I pazienti descritti sono veri "sofferenti" (la radice della parola paziente), e la loro vita è stata gravemente disturbata. Come già detto, si tratta di un lavoro particolarmente rilevante in un momento in cui la tecnologia eolica e le sue applicazioni sono in aumento in tutto il mondo. Allo stesso tempo mette in guardia i medici sul potenziale patologico delle vibrazioni a bassa frequenza e li incoraggia ad esaminare minuziosamente gli altri possibili effetti collaterali delle nuove tecnologie.

Mi auguro che questo studio, quando sarà pubblicato, stimolerà la ricerca non solo sull'azione deleteria delle vibrazioni a bassa frequenza sugli esseri umani, ma anche sulla fauna in generale. Spero inoltre che i complessi sintomatologici descritti siano studiati in modo più approfondito, in modo da ottenere una maggiore conoscenza dell'organismo umano in termini di fisiologia e patofisiologia. Sono certo che studiando le forze fisiche che hanno un impatto sugli esseri umani contribuirà in modo importante alla comprensione della fisiologia e degli stati patologici. Lo studio rivela alla comunità medica la problematica della vibrazione a bassa frequenza. Anche altre forze fisiche, sia meccaniche che elettriche, potrebbero ricoprire un ruolo in certe patologie umane. Questo studio potrebbe incoraggiare a riconoscere ciò che la ricerca ha ottenuto studiando stati patologici attraverso l'analisi delle forze fisiche.

Dato che l'analisi di queste forze è al momento al di fuori del modello medico della diagnosi di patologie, molte di queste persone sofferenti sono state etichettate come persone con problemi puramente psicologici. L'autrice ha fornito una base per descrivere questo gruppo di complessi sintomatologici come patofisiologici. A lei i miei più sentiti elogi.

JOEL F. LEHRER, MD, Fellow dell'American College of Surgeons, Clinical Professor of Otolaryngology, University of Medicine & Dentistry of New Jersey. Già professore di otorinolaringoiatria, Mount Sinai School of Medicine, New York, New York.

29 giugno 2008

Mi congratulo con la Dott.ssa Pierpont per la sua ricerca sulla serie di casi di sindrome da turbina eolica, per come è stata concepita, per la raccolta dei dati, per l' analisi e l'elaborazione. Come epidemiologo mi rendo pienamente conto del suo sforzo davvero notevole, un lavoro che, oltre ad essere ben fatto, ha dimostrato pieno rispetto per l'onestà nella ricerca. Dati i sospetti iniziali dell'autrice su questo problema, il suo alto livello di integrità scientifica è stato dimostrato sia nel modo in cui ha strutturato la ricerca, sia nell'elaborazione dei dati, entrambi di altissimo livello.

Il progetto è allo stesso tempo degno di nota e limitato (cosa di cui l'autrice è perfettamente cosciente). Prevedo numerosi risultati degni di nota dall'esemplare ed eccezionale presentazione della relazione sulla sindrome da turbina eolica presentata nella sua prospettiva di medico della comunità.

1) Creazione di una definizione dei casi di sindrome da turbina eolica. L'autrice ha avviato una prima importante fase necessaria a far diventare un "motivo di preoccupazione" un "argomento che può essere studiato". Ha presentato una chiara definizione dei casi di sindrome da turbina eolica, e il riconoscimento e la definizione di un nuovo sintomo da lei documentato e denominato disturbo vestibolare con vibrazioni viscerali (VVVD).

2) Creazione di una lista ponderata di punti da chiarire in una ricerca futura sulla sindrome da turbina eolica. Attraverso il suo forte ed evidente impegno nella ricerca della verità in questo ambito, l'autrice ha fornito un ricco elenco di istruzioni fruibili da altre persone che vogliano seguire questa linea di ricerca. Questa è una cosa che gli studiosi riescono ad ottenere unicamente in seguito a un profondo coinvolgimento intellettuale nella ricerca.

3) Presentazione nitida di un elenco intelligente delle limitazioni dello studio sulla serie di casi. Ispira fiducia nel lettore il fatto che l'autrice abbia veramente condotto un studio mirato a far luce su questo argomento. Ciò richiede sempre trasparenza e intuizione da parte del ricercatore che conosce meglio di chiunque altro la serie di eventuali limitazioni, da quelle minori a quelle maggiori, del proprio studio.

L'autrice si rende perfettamente conto che la limitazione principale di questo studio è la mancanza di "generalizzazione" dei risultati specifici per popolazioni più ampie, soprattutto a causa degli specifici criteri di scelta dei soggetti da studiare (appropriati e necessari) nella serie di casi. Non occorre preoccuparsene, anzi è qualcosa da apprezzare e su cui costruire, poiché questa limitazione è inerente a qualsiasi indagine epidemiologica di fase iniziale di un'area specifica ancora in evoluzione.

Sono state poste base eccezionali, oneste e di elevata qualità su cui altri potranno costruire in fasi successive della ricerca scientifica. Ciò facendo, l'autrice ha reso un lodevole, minuzioso, attento, onesto e significativo contributo allo studio di (quella che ora possiamo chiamare) sindrome da turbina eolica.

RALPH V. KATZ, DMD, MPH, PhD, Fellow of the American College of Epidemiology, Professore e presidente del Dipartimenti di epidemiologia e promozione della salute, New York University College of Dentistry, New York, New York

5 ottobre 2008

La Dott.ssa Pierpont ha raccolto una solida serie di casi studio sugli effetti deleteri per la salute ed il benessere dei numerosi individui che vivono nelle vicinanze di grandi turbine eoliche. Ha inoltre preso in considerazione studi medici che permettono di ritenere plausibile che ci sia un meccanismo fisiologico che connette direttamente il rumore a bassa frequenza e vibrazioni, come quelle prodotte dalle turbine eoliche (che di per sé non vengono necessariamente considerate irritanti), a effetti potenzialmente debilitanti sull'orecchio interno e su altri sistemi sensori connessi con l'equilibrio e il senso della posizione. A quanto sembra dunque gli effetti hanno una componente fisiologica, piuttosto che essere di ordine esclusivamente psicologico.

Saranno necessarie osservazioni più ampie e statisticamente controllate per scoprire a quale distanza dalle turbine compaiano i loro effetti deleteri e in quale misura colpiscano la popolazione. Tuttavia è già chiaro che molte persone sono colpite a distanze molto maggiori delle minime attualmente previste tra le turbine e le abitazioni. Di conseguenza, in attesa di altri studi sulla "sindrome da turbina eolica" recentemente esaminata, sarebbe prudente stabilire distanze molto maggiori dalle case, come criterio per l'installazione di nuove turbine. La documentazione della sindrome rappresenta una prova che le attuali distanze di sicurezza stabilite sono terribilmente inadeguate.

HENRY S. HORN, PhD, Professore di ecologia e biologia evolutiva e Associato presso il Princeton Environmental Institute, Princeton University, Princeton, New Jersey

17 ottobre 2008

# Effects of industrial wind turbine noise on sleep and health

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## Abstract

**Industrial wind turbines (IWTs) are a new source of noise in previously quiet rural environments. Environmental noise is a public health concern, of which sleep disruption is a major factor. To compare sleep and general health outcomes between participants living close to IWTs and those living further away from them, participants living between 375 and 1400 m (n = 38) and 3.3 and 6.6 km (n = 41) from IWTs were enrolled in a stratified cross-sectional study involving two rural sites. Validated questionnaires were used to collect information on sleep quality (Pittsburgh Sleep Quality Index — PSQI), daytime sleepiness (Epworth Sleepiness Score — ESS), and general health (SF36v2), together with psychiatric disorders, attitude, and demographics. Descriptive and multivariate analyses were performed to investigate the effect of the main exposure variable of interest (distance to the nearest IWT) on various health outcome measures. Participants living within 1.4 km of an IWT had worse sleep, were sleepier during the day, and had worse SF36 Mental Component Scores compared to those living further than 1.4 km away. Significant dose-response relationships between PSQI, ESS, SF36 Mental Component Score, and log-distance to the nearest IWT were identified after controlling for gender, age, and household clustering. The adverse event reports of sleep disturbance and ill health by those living close to IWTs are supported.**

*Keywords: Health, industrial wind turbines, noise, sleep*

## Introduction

Environmental noise is emerging as one of the major public health concerns of the twenty-first century.[1] The drive to 'renewable', low-carbon energy sources, has resulted in Industrial Wind Turbines (IWTs) being sited closer to homes in traditionally quiet rural areas to reduce transmission losses and costs. Increasing numbers of complaints about sleep disturbance and adverse health effects have been documented,[2-4] while industry and government reviews have argued that the effects are trivial and that current guidance is adequate to protect the residents.[5,6] We undertook an epidemiological study to investigate the relationship between the reported adverse health effects and IWTs among residents of two rural communities.

## Methods

### General study design

This investigation is a stratified cross-sectional study involving two sites: Mars Hill and Vinalhaven, Maine, USA. A questionnaire was offered to all residents meeting the participant-inclusion criteria and living within 1.5 km of an industrial wind turbine (IWT) and to a random sample of residents, meeting participant inclusion criteria, living 3 to 7 km from an IWT between March and July of 2010. The protocol was reviewed and approved by Institutional Review Board Services, of Aurora, Ontario, Canada.

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### Questionnaire development

Adverse event reports were reviewed, together with the results of a smaller pilot survey of Mars Hill residents. A questionnaire was developed, which comprised of validated instruments relating to mental and physical health (SF-36v2)[7] and sleep disturbance ((Pittsburgh Sleep Quality Index (PSQI)[8] and the Epworth Sleepiness Scale (ESS)[9]). In addition, participants were asked before-and-after IWT questions about sleep quality and insomnia, attitude toward IWTs, and psychiatric disorders. A PSQI score > 5 was taken to indicate poor sleep and an ESS score > 10 was taken to indicate clinically relevant daytime sleepiness.[1-4] Responses to functional and attitudinal questions were graded on a five-point Likert scale with 1 representing the least effect and 5 the greatest. The questionnaire is available on request.

### Study sites and participant selection

The Mars Hill site is a linear arrangement of 28 General Electric 1.5 megawatt turbines, sited on a ridgeline. The Vinalhaven site is a cluster of three similar turbines sited on a low-lying, tree-covered island. All residents living within 1.5 km of an IWT, at each site, were identified via tax maps, and approached either door-to-door or via telephone and asked to participate in the study (near group). Homes were visited thrice or until contact was made. Those below the age of 18 or with a diagnosed cognitive disorder were excluded. A random sample of households in similar socioeconomic areas, 3 to 7 km away from IWTs at each site, were chosen to participate in the study to allow for comparison (far group). The households were approached sequentially until a similar number of participants were enrolled. A nurse practitioner supervised the distribution and ensured completion of the questionnaires.

Simultaneous collection of sound levels during data collection at the participants' residences was not possible, but measured IWT sound levels at various distances, at both sites, were obtained from publically available sources. At the Mars Hill site, a four quarter study was conducted and data from all four seasons were reported by power outputs at several key measurement points. The measurement points were located on or near residential parcels. The predicted and measured levels at full power were derived from figures in the Sound Level Study, Compilation of Ambient and Quarterly Operations Sound Testing, and the Maine Department of Environmental Protection Order No. L-21635-26-A-N. Measured noise levels versus distance at Vinalhaven were taken over a single day in February 2010, with the turbines operating at less than full power in moderate-to-variable northwest winds aloft (R and R, personal communication, 2011). Table 1 shows the estimated and measured noise levels at locations of varying distances and directions from the turbines at Mars Hill and Vinalhaven.

## Data handling and validation

The Principal Investigator (Michael Nissenbaum, MD) did not handle data at any point in the collection or analysis phase. Questionnaire results were coded and entered into a spreadsheet (Microsoft Excel 2007). Each questionnaire generated over 200 data elements. The distance from each participant's residence to the nearest IWT was measured using satellite maps. The SF36-V2 responses were processed using Quality Metric Health Outcomes™ Scoring Software 3.0 to generate Mental (MCS) and Physical (PCS) Component Scores.

Data quality of the SF36-V2 responses was determined using QualityMetric Health Outcomes™ Scoring Software 3.0. All SF36-V2 data quality indicators (completeness, response range, consistency, estimable scale scores, internal consistency, discriminant validity, and reliable scales) exceeded the parameter norms. SF 36-V2 missing values were automatically accommodated by the scoring systems (99.9% questions were completed). No missing values were present for other parameters (ESS, PSQI, psychiatric and attitudinal observations, and demographics).

**Table 1: Measured and predicted noise levels at Mars Hill and Vinalhaven**

| Mars hill | | | |
|---|---|---|---|
| Distance to nearestturbine (m)[1] | Predicted max. LAeq 1 hr[1] | Measured noise LAeq 1 hr[1] | |
| | | Average | Range |
| 244 | 51 | 52 | 50 – 57 |
| 320 | 48 | 50 | 48 – 53 |
| 366 | 47 | 49 | 47 – 52 |
| 640 | 42 | 44 | 40 – 47 |
| 762 | 41 | 43 | 41 – 46 |
| 1037 | 39 | 41 | 39 – 45 |
| 1799 | 35 | 37 | 32 – 43 |

| Vinalhaven | | |
|---|---|---|
| Distance to nearest turbine (m)[2] | Measured Noise LAeq[2] | |
| | Trend Average | Range |
| 152 | 53 | 51 – 61 |
| 366 | 46 | 38 – 49 |
| 595 | 41 | 39 – 49 |
| 869 | 38 | 32 – 41 |
| 1082 | 36 | 34 – 43 |

[1] Values read or derived from report figures; accuracy + /- 50 m and + /- 1 Db [2] Values obtained with wind turbine noise dominating the acoustical environment, two-minute measurements during moderate-to-variable northwest winds aloft (less than full power)

## Statistical analysis

All analyses were performed using SAS 9.22.[10] Descriptive and multivariate analyses were performed to investigate the effect of the main exposure variable of interest (distance to the nearest IWT) on the various outcome measures. Independent variables assessed included the following: Site (Mars Hill, Vinalhaven); Distance to IWT (both as a categorical and continuous variable); Age (continuous variable); Gender (categorical variable). The dependent variables assessed included the following: Summary variables — Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI), SF36-V2 Mental Component Score (MCS), SF36-V2 Physical Component Score (PCS); Before and after parameters — sleep, psychiatric disorders (both self-assessed and diagnosed by a physician), attitude toward IWTs; and Medication use (both over-the-counter and prescription drugs). A $P$ value of $< 0.05$ was regarded as being statistically significant.

# Results

## Study participants

Thirty-three and 32 adults were identified as living within 1500 m of the nearest IWT at the Mars Hill (mean 805 m, range 390 – 1400) and Vinalhaven sites (mean 771 m range 375 – 1000), respectively. Twenty-three and 15 adults at the Mars Hill and Vinalhaven sites respectively, completed the questionnaires. Recruitment of participants into the far group continued until there were similar numbers as in the near group, 25 and 16 for Mars Hill and Vinalhaven, respectively [Table 2].

## Statistical results

The binomial outcomes were assessed using either the GENMOD procedure with binomial distribution and a logit link; or when cell frequencies were small (< 5), Fisher's Exact Test. When assessing the significance between variables with a simple score outcome (e.g., 1 – 5), the exact Wilcoxon Score (Rank Sums) test was employed using the NPAR1WAY procedure. Continuous outcome variables were assessed using the GENMOD procedure with normal distribution. When using the GENMOD procedure, age, gender, and site were forced into the model as fixed effects. The potential effect of household clustering on statistical significance was accommodated by using the REPEATED statement. Effect of site as an effect modifier was assessed by evaluating the interaction term (Site*Distance).

Participants living near IWTs had worse sleep, as evidenced by significantly greater mean PSQI and ESS scores [Table 3]. More participants in the near group had PSQI > 5 ($P = 0.0745$) and ESS scores > 10 ($P = 0.1313$), but the differences did not reach statistical significance. Participants living near IWTs were significantly more likely to report an improvement in sleep quality when sleeping away from home.

**Table 2: Demographic data of Mars Hill and Vinalhaven study participants**

| | Distance (m) from residence to nearest IWT (mean) | | | |
|---|---|---|---|---|
| Parameter | 375 – 750 (601) | 751 – 1400 (964) | 3300 – 5000 (4181) | 5300 – 6600 (5800) |
| Sample size | 18 | 20 | 14 | 27 |
| Household clusters | 11 | 12 | 10 | 23 |
| Mean age | 50 | 57 | 65 | 58 |
| Male / Female | 10 / 8 | 12 / 8 | 7 / 7 | 11 / 16 |
| Mean time in home[1] | 14 | 21 | 30 | 24 |

[1] Years that study participants lived in the home

The near group had worse mental health as evidenced by significantly higher mean SF36 MCS ($P = 0.0021$) [Table 3]. There was no statistically significant difference in PCS ($P = 0.9881$). Nine participants in the near group reported that they had been diagnosed with either depression or anxiety since the start of turbine operations, compared to none in the far group. Nine of the 38 participants in the near group reported that they had been prescribed new psychotropic medications since the start of turbine operations compared with three of 41 in the far group ($P = 0.06$).

The ESS, PSQI, and SF36 scores were modeled against distance from the nearest IWT (Score = ln (distance) + gender + age + site [controlled for household clustering]), and the results are shown in Figures 1–3. In all cases, there were clear and significant dose-response relationships ($P < 0.05$), with the effect diminishing with increasing log-distance from IWTs. Log-distance fit the health outcomes better than distance. This was expected given that noise drops off as the log of distance. Measured sound levels were plotted against distance at the two sites on Figures 1-3.

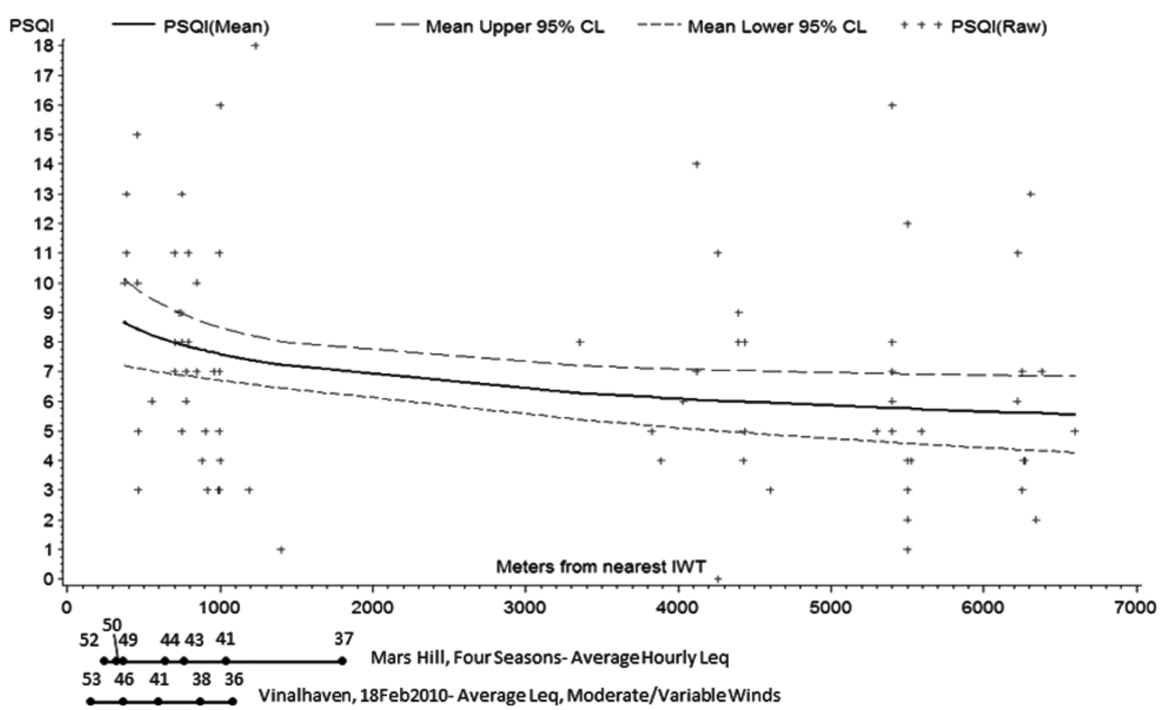


**Figure 1: Modeled Pittsburgh Sleep Quality Index (PSQI) versus distance to nearest IWT (mean and 95% confidence limits) Regression equation: PSQI = ln (distance) + sex + age + site [controlled for household clustering]. Ln (distance) *p*-value = 0.0198**

**Table 3: Sleep and mental health outcomes of the study participants grouped by distance from the nearest IWT**

| | Distance (m) from residence to nearest IWT (mean) | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | 375-750 (601) | 751-1400 (964) | 375-1400 (792) | 3300-5000 (4181) | 5300-6600 (5800) | 3000-6600 (5248) | P-Value[1] |
| Mean PSQI[2] | 8.7 | 7.0 | 7.8 | 6.6 | 5.6 | 6.0) | 0.0461 |
| % PSQI score > 5[3] | 77.8 | 55.0 | 65.8 | 57.1 | 37.0 | 43.9 | 0.0745 |
| Mean ESS[4] | 7.2 | 8.4 | 7.8 | 6.4 | 5.3 | 5.7 | 0.0322 |
| % with ESS score > 10[5] | 16.7 | 30.0 | 23.7 | 14.3 | 7.4 | 9.8 | 0.1313 |
| Mean worsening sleep score post IWTs[6] | 3.2 | 3.1 | 3.1 | 1.2 | 1.4 | 1.3 | < .0001 |
| Improved sleep when away from IWTs | 9 / 14 | 5 / 14 | 14 / 28 | 1 / 11 | 1 / 23 | 2 / 34 | < .0001 |
| % New sleep medications post IWTs | 11.1 | 15.0 | 13.2 | 7.1 | 7.4 | 7.3 | 0.4711 |
| New diagnoses of insomnia | | | 2 | | | 0 | |
| Mean SF36 MCS | 40.7 | 43.1 | 42.0 | 50.7 | 54.1 | 52.9 | 0.0021 |
| % Wishing to move away post IWTs | 77.8 | 70.0 | 73.7 | 0.0 | 0.0 | 0.0 | < .0001 |

[1] Testing difference of 375 – 1400 m group with 3000 – 6600 m group [2] Pittsburgh Sleep Quality Index [3] PSQI > 5 is considered a 'poor sleeper' [4] Epworth Sleepiness Scale [5] About 10 – 20 percent of the general population has ESS scores > 10 [6] (New sleep problems + Worsening sleep problem)/2; Strongly Agree (5) - Strongly disagree (1)

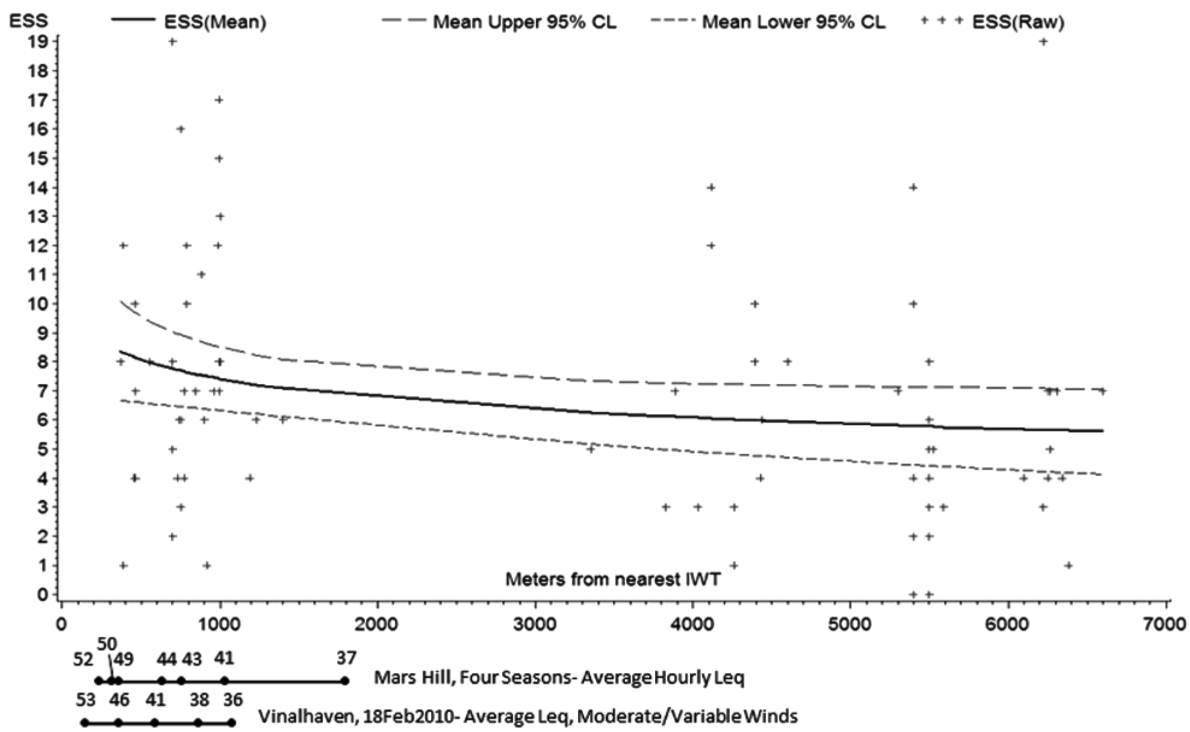


**Figure 2: Modeled Epworth Sleepiness Scale (ESS) versus Distance to nearest IWT (mean and 95% confidence limits) Regression equation: ESS = ln (distance) + sex + age + site [controlled for household clustering)]. ln (distance) p-value = 0.0331**

There were no statistically significant differences between the near and far groups with respect to age, gender, or duration of occupation. In addition, Site, and Site*Distance were not significant, indicating that the modeled exposure-outcome relationships were similar across both sites.

## Discussion

This study supports the conclusions of previous studies, which demonstrate a relationship between proximity to IWTs and the general adverse effect of 'annoyance',[11-13] but differs in demonstrating clear dose-response relationships in important clinical indicators of health including sleep quality, daytime sleepiness, and mental health. The levels of sleep disruption and the daytime consequences of increased sleepiness, together with the impairment of mental health and the dose-response relationships observed in this study (distance from IWT vs. effect) strongly suggest that the noise from IWTs results in similar health impacts as other causes of excessive environmental noise[1].

The degree of effect on sleep and health from IWT noise seems to be greater than that of other sources of

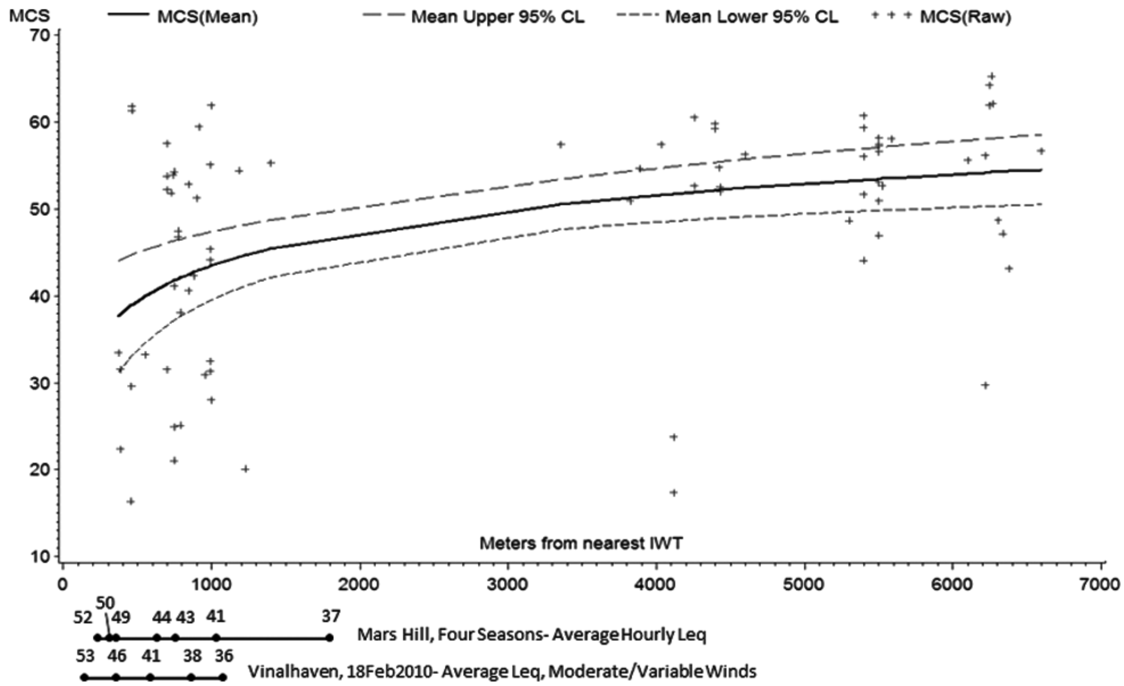


**Figure 3: Modeled SF36 Mental Component Score (MCS) versus Distance to nearest IWT (mean and 95% confidence limits) Regression equation: MCS = ln (distance) + sex + age + site [controlled for household clustering]. ln (distance) p-value = 0.0014**

environmental noise, such as, road, rail, and aircraft noise. Bray and James have argued that the commonly used noise metric of LAeq (averaged noise level adjusted to human hearing) is not appropriate for IWT noise, which contains relatively high levels of low frequency sound (LFN) and infrasound with impulsive characteristics.[14] This has led to an underestimation of the potential for adverse health effects of IWTs.

## Potential biases

Reporting and selection biases in this study, if they existed, may have underestimated the strength of the association between distance to IWTs and health outcomes. Both Mars Hill and Vinalhaven residents gain financially from the wind projects, either through reduced electricity costs and / or increased tax revenues. The fear of reducing property values was also cited as a reason for downplaying the adverse health effects. Conversely, the possibility of legal action could result in symptoms being over stated. It was clear to the respondents that the questionnaire was directed at investigating adverse health effects potentially associated with IWT noise and no distractor questions were included. Nevertheless, given the large differences in reported adverse health effects between participants living within 1400 m and those living beyond 3300 m of an IWT, we do not believe that bias alone could have resulted in the differences demonstrated between the groups. In addition, the finding of strong dose-response relationships with log-distance, together with extensive sub-analyses using survey questions more and less likely to be influenced by bias demonstrating similar results, further support the existence of causative associations.

Visual impact and attitude are known to affect the psychological response to environmental noise.[11,15,16] At both sites, turbines are prominent features of the landscape and were visible to a majority of respondents; at Mars Hill, IWTs are sited along a 200 m high ridge, and Vinalhaven is a flat island. The visual impact on those living closest to turbines was arguably greater than on those living some distance away. Most residents welcomed the installation of IWTs for their proposed financial benefits and their attitudes only changed once they began to operate and the noise and health effects became apparent. Pedersen estimates that, with respect to annoyance, 41% of the observed effects of IWT noise could be attributed to attitude and visual impact.[11] The influence of these factors on other consequences, such as the health effects investigated in this study, remains to be determined. Even as these factors may have contributed to the reported effects, they are clearly not the sole mechanism and health effects are certain.

## Mechanisms

A possible mechanism for the observed health effects is an effect on sleep from the noise emitted by IWTs. Industrial wind turbines emit high levels of noise with a major low frequency component. The noise is impulsive in nature and variously described as ‘swooshing’ or ‘thumping’.[12] The character, volume, and frequency of the noise vary with changes in wind speed and direction. Industrial wind turbine noise is more annoying than road, rail, and aircraft noise, for the same sound pressure, presumably due to its impulsive character.[12,15] Pedersen concludes that it is noise that prevents restoration, that those subjected to it are unable to find psychological recovery in their homes because of its intrusive nature.[16] Noise can affect sleep by preventing sleep onset or return to sleep following spontaneous or induced awakening. Clearly, attitude and psychological factors such as noise sensitivity may be important in influencing the ability to fall asleep, but it should be noted that noise sensitivity is, in part, heritable.[17] Noise also affects sleep by inducing arousals, which fragment sleep, reducing its quality and leading to the same consequences as sleep deprivation.[18] There is good evidence that road, rail, and aircraft noise induce arousals and lead to daytime consequences and there is no reason to suppose that IWT noise will not have a similar effect.[19-23] A recent study on the likelihood of different hospital noises that induce an arousal shows a considerable effect of sound character, with impulsive noises being more likely to induce an arousal.[24] It has also been shown that there is individual variability in the likelihood of an arousal in response to noise, which may be predicted from a spindle index, a measure of sleep quality.[25]

ESS assesses daytime sleepiness from the self-assessed propensity to fall asleep in different situations averaged over several weeks.[9] It is widely used in sleep medicine to assess daytime sleepiness, and scores in excess of 10 are deemed to represent clinically relevant excessive daytime sleepiness. If sleep is only disrupted occasionally, the ESS will not be affected, as the sleep deficit can be compensated on other nights. Changes in the ESS score observed in this study imply that sleep has been disrupted to a degree where compensation is not possible in at least some participants. PSQI also examines the sleep quality averaged over a period of weeks, scores in excess of 5 are deemed to represent poor quality sleep.[8] An individual's score will not be significantly affected by occasional disrupted nights, thus confirming the conclusions drawn from the ESS data. It is noteworthy also that significant changes in ESS and PSQI have been observed, despite the scatter in values indicative of the typical levels of impaired sleep found in the general population.[8,9]

Other mechanisms than sleep disruption cannot be excluded as an explanation for the psychological and other changes observed. Low frequency noise, and in particular, impulsive LFN, has been shown to be contributory to the symptoms of 'Sick Building Syndrome,' which has similarities with those reported here.[26,27] Salt has recently proposed a mechanism, whereby, infrasound from IWTs could affect the cochlear and cause many of the symptoms described.[28]

We assessed causality using a well-accepted framework.[29] Although the measured parameters (ESS, PSQI, and SF36) assess the current status, the evidence of the respondents is that the reported changes have followed the commencement of IWT operation. This is supported by the reported preferences of the residents; the great majority of those living within 1.4 km expressed their desire to move away as a result of the start of turbine operations. However, a study of the same population before and after turbine operation will be necessary to confirm our supposition. We believe that there is good evidence that a time sequence has been established. The association between distance to IWT and health outcome is both statistically significant and clinically relevant for the health outcomes assessed, suggesting a specific association between the factors. Given that this is the first study investigating the association between IWTs and a range of health outcomes, the consistency and replication to prove causation is limited. However, this study includes two different study populations living next to two different IWT projects. Despite these differences, the study site was not a significant effect modifier among any of the measured outcomes. In addition, adverse health effects similar to those identified in this study among those living near IWTs, have been documented in a number of case-series studies and surveys.[2-4,30] Finally, causal association can be judged by its coherence with other known facts about the health outcomes and the causal factor under study. The results of this study are consistent with the known effects of other sources of environmental noise on sleep.

The data on measured and estimated noise levels were not adequate to construct a dose-response curve and to determine an external noise level below which sleep disturbance will not occur. However, it is apparent that this value will be less than an average hourly LAeq of 40 dBA, which is the typical night time value permitted under the current guidance in most jurisdictions.

## Conclusions

We conclude that the noise emissions of IWTs disturbed the sleep and caused daytime sleepiness and impaired mental health in residents living within 1.4 km of the two IWT installations studied. Industrial wind turbine noise is a further source of environmental noise, with the potential to harm human health. Current regulations seem to be insufficient to adequately protect the human population living close to IWTs. Our research suggests that adverse effects are observed at distances even beyond 1 km. Further research is needed to determine at what distances risks become negligable, as well as to better estimate the portion of the population suffering from adverse effects at a given distance.

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# Evaluating the impact of wind turbine noise on health-related quality of life

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### Abstract

**We report a cross-sectional study comparing the health-related quality of life (HRQOL) of individuals residing in the proximity of a wind farm to those residing in a demographically matched area sufficiently displaced from wind turbines. The study employed a nonequivalent comparison group posttest-only design. Self-administered questionnaires, which included the brief version of the World Health Organization quality of life scale, were delivered to residents in two adjacent areas in semirural New Zealand. Participants were also asked to identify annoying noises, indicate their degree of noise sensitivity, and rate amenity. Statistically significant differences were noted in some HRQOL domain scores, with residents living within 2 km of a turbine installation reporting lower overall quality of life, physical quality of life, and environmental quality of life. Those exposed to turbine noise also reported significantly lower sleep quality, and rated their environment as less restful. Our data suggest that wind farm noise can negatively impact facets of HRQOL.**

*Keywords: Amenity, annoyance, health-related quality of life, sleep quality, wind turbine noise*

## Introduction

Wind turbines transform wind energy into electricity, a practice dating back over 100 years. However, in the last decade industrial-scale harvesting of wind energy has increased, driven by a desire to generate sustainable energy and to lessen the impact of fossil fuel depletion. Whether located in isolation or as components of a "wind farm", wind turbines were initially welcomed by many communities due to their environmental credentials, though reference to the mainstream media shows that public opposition to wind turbines has increased substantially in the past few years.[1] Complaints against established wind farms, or concern elicited by proposed wind farms, focus on the noise they produce, or the visual impact they have on the environment.

The desire to maximize electricity production while minimizing transmission costs means that in many countries wind farms have been constructed in semirural areas (also known as "greenbelt" or "life-style" areas) close to major towns and cities. Noise from wind farms located in semirural areas is of interest because it is typically a low amplitude noise impeding on a well-characterized and generally cherished soundscape. Consequently, there has been considerable debate over whether wind farm noise poses a significant health threat to those living in their vicinity. It has been suggested that wind turbines can directly impact health via the emission of low-frequency sound energy (i.e., infrasound below 20 Hz), though this is currently an area of controversy.[2,3] Additionally, wind turbines may compromise health by producing sound that is annoying and/or can disturb sleep. In this respect, it can be classified as community noise along side industrial or transportation noise. When built in semirural settings, the visual impact of wind farms can also degrade amenity and interact with wind turbine noise to exacerbate annoyance reactions,[4] possibly due to a violation of the landscape--soundscape continuum constructed by those who choose to live in these areas.[5]

Figure 1 represents a simple model informed by the literature[6,7] demonstrating that, in the semirural context, there are feasible mechanisms by which wind turbine exposure can degrade health and well-being. Turbine noise can lead directly to annoyance and sleep disturbance (primary health effects), or can induce annoyance by degrading amenity. Additionally, the trait of noise sensitivity, which describes individuals who are more likely to pay attention to sound, evaluate sound negatively, and have stronger emotional reactions to noise,[8] constitutes a major risk factor. The secondary heath effects would be immediate reductions in

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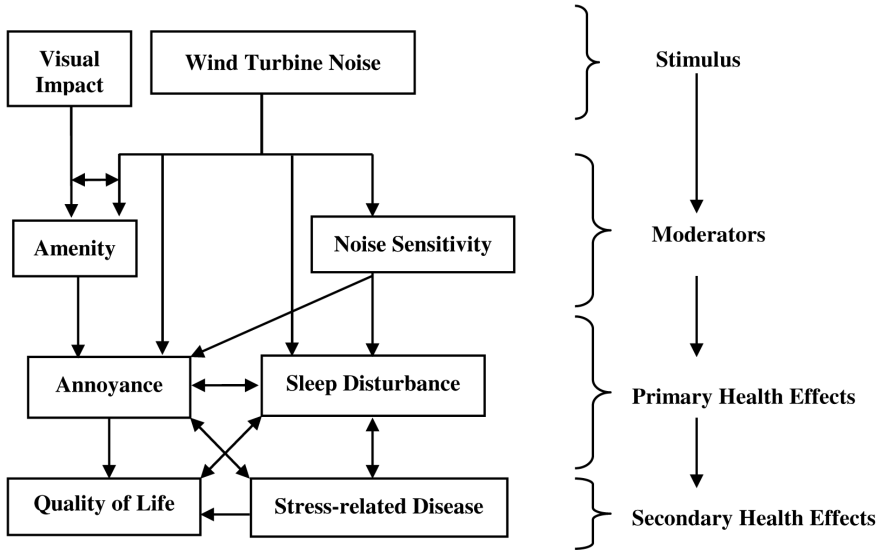


**Figure 1: A schematic representation of the relationship between wind turbines and health in a semirural setting. The multiplicity of relationships emerges due to variability in the response of individuals to noise**

general well-being, with stress-related disease emerging from chronic annoyance and sleep disturbance. Irrespective of source, chronic noise exposure is a psychosocial stressor that can induce maladaptive psychological responses and negatively impact health via interactions between the autonomic nervous system, the neuroendocrine system, and the immune system.[7] A chronic stress response will, in turn, degrade quality of life [Figure 1].

Quantifying the impact of wind turbines on individual health will inform wind turbine operational guidelines, and in this respect constitutes an important process that is currently not far advanced. A variety of outcome measures have been proposed to assess the impacts of community noise, including annoyance, sleep disturbance, cardiovascular disease, and cortisol levels.[9] An alternative approach to health assessment involves the subjective appraisal of health-related quality of life (HRQOL), a concept that measures general well-being and well-being in the physical, psychological, and social domains. Because changes in HRQOL are expected to closely co-vary with changes in health, the WHO recommends the use of HRQOL measures as an outcome variable, arguing that the effects of noise are strongest for those outcomes classified under HRQOL rather than illness.[9] HRQOL is related to health by the WHO (1948) definition of health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity," and can be considered as an operationalization of the well-being concept.[10]

There is scientific evidence linking community noise to health problems.[7,9,10] The WHO reports that chronic noise-induced annoyance and sleep disturbance can compromise health and HRQOL.[9,11,12] However, there has been little research examining the relationship between noise and HRQOL. An exception is Dratva *et al.*,[13] who, using the Short Form (SF36) health survey, reported an inverse relationship between annoyance from traffic noise and HRQOL. They argued that HRQOL would be expected to co-vary more with annoyance than with noise level as level is generally a poor predictor of the human response to noise, and its role in health is commonly overemphasized. As alternatives to noise level, other factors associated with the listener should be considered,[6] including the perceived control a person has over the noise, as well as their attitudes, personality, and age (all of which could be added to Figure 1 as moderators).

This exploratory study examines the association between HRQOL and proximity to an industrial wind farm in a semirural area, adding to the small number of peer-reviewed studies into the health impacts of wind turbines that are only beginning to appear in the literature. Case studies supported by qualitative analyses[2,14,15] suggest a negative relationship between wind turbine noise and well-being. There have been no previous quantitative investigations of the impact of wind farms on HRQOL, though correlations have been observed between wind turbine noise, annoyance, and sleep disruption.[16,17] Given these findings, and with reference to Figure 1, it would be expected that both mean amenity and sleep satisfaction scores would be lower in individuals residing around turbines, and that the proportion of individuals annoyed by noise would be greater for those exposed to turbines than those not. Additionally, lowered amenity and greater annoyance should result in lower mean HRQOL domains in those residing close to wind turbines.

## Materials and Methods

### Design

A nonequivalent comparison group posttest-only study design was utilized. Strict socioeconomic matching was undertaken using the New Zealand Deprivation Index 2006,[18] as described elsewhere.[19] Both areas are classified as semirural,[20] with a population density of less than 15 people per square kilometer.

## Sample

Samples were drawn from two demographically matched areas differing only in their distances from a wind farm in the Makara Valley, a coastal area 10 km west of New Zealand's capital city, Wellington. The Makara Valley is characterized by hilly terrain, with long ridges running 250-450 m above sea level, on which 66 125 m high wind turbines are positioned as part of the "West Winds" project. Figure 2 is a map showing the positions of a subset of wind turbines relative to some of the houses in valley. The first sample (the *Turbine* group) was drawn from residents in the South Makara Valley who resided in 56 houses located within 2 km of a wind turbine. A comprehensive noise survey of the area was undertaken independently, indicating intrusive elements of the turbine noise such as the "rumble-thump."[21] The Makara turbines, operational since May 2009, have measured levels that are consistent with levels reported in European studies,[17] in which typical noise exposures from wind turbines ranged from between 24 dB(A) and 54 dB(A). Long-term measurements undertaken by the wind farm developers at various residences show that while average outdoor levels ($L_{95\ (10\ min)}$ dB(A)) are largely compliant with consent conditions, they still range between 20 dB(A) and 50 dB(A) depending on meteorological conditions.[22] The second sample (the *Comparison* group) was taken from residents in 250 houses in a geographically and socioeconomically matched area, but which were located at least 8 km from any wind farm in the region.

## Questionnaire

The coversheet of the questionnaire bore the title *2010 Well-being and Neighbourhood Survey*, designed to mask the true intent of the study. Each house received two copies of the questionnaire. Potential participants were invited to participate in the research investigating their place of living and their well-being if they resided at the address to which the questionnaire had been delivered and if they were 18 years or older. The order of the questions was a prime consideration: HRQOL (26 items), amenity (2 items), neighbourhood problems (14 items), annoyance (7 items), demographic information (7 items), and a single item probing noise sensitivity. All scale items were presented on a numbered five-point scale with appropriate descriptors anchoring the terminals. Self-reported HRQOL was measured using the abbreviated version of the WHOQOL-BREF which affords composite measures of physical (7 items), psychological (6 items), and social (3 items) HRQOL. Additionally, the WHOQOL-BREF has two generic items asking about general health and overall quality of life, and an additional domain measuring and

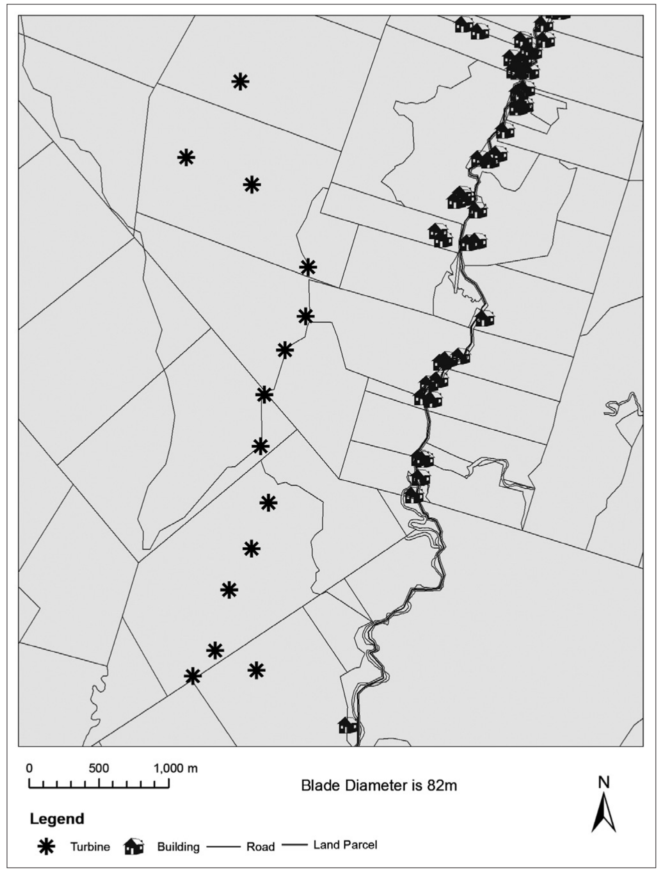


**Figure 2: Map showing a part of the Makara Valley and the relative distances between houses and 14 of the 66 turbines. The wind turbines (Siemens SWT-2.3-82 VS) have 68 m high towers and rotor diameters of 82 m (Map generated by Rachel Summers, and displayed with permission).**

environmental QOL (8 items). The two amenity items were: "I am satisfied with my neighbourhood/living environment" and "My neighbourhood /living environment makes it difficult for me to relax at home." A modified neighbourhood problem scale[23] consisted of 14 distracter items that were not relevant to the current study and were not included in the analysis. Seven items on annoyance were included, four distracter items asking about air quality, and three items probing annoyance to traffic, other neighbours, or other noise (*please specify*). Additionally, participants were asked if they were not noise sensitive, moderately noise sensitive, or very noise sensitive. The questionnaire terminated with an open-ended item asking "If you would like to share any comments relating to your neighbourhood or this survey then please do so in the box below." Participants were asked to respond to all items and to return surveys by post in the prepaid envelopes provided.

## Demographics

Self-reported age and sex measures were obtained and self-reported level of educational status used as a further indicator of socioeconomic status. Additionally, participants were asked what their current employment status was, and whether they were currently ill or had a medical condition.

Participants were also asked how long they had lived at their current residence.

### Statistical analysis

Analysis commenced after an evaluation of each scale's psychometric properties, including inspection for floor and ceiling effects and tests of internal consistency (Cronbach's alpha) and to validate dimensionality (corrected item-total correlations). Differences in HRQOL and amenity between the turbine and comparison groups were calculated using univariate analysis of covariance (ANCOVA), with length of residence selected *a priori* as a covariate. All testing was undertaken in accordance with Tabachnick and Fidell's[24] guidelines for testing between groups with unequal sample sizes, and Bonferroni corrections were applied where appropriate. Because of the unequal sizes between the two groups the assumptions of normality and homogeneity of variance were assessed carefully. Five cases were excluded from the comparison group because they were multivariate outliers as defined by extreme Mahalanobis distances, with response set acquiescence clearly evident in all five cases.

**Table 1: Demographic profile of the turbine and comparison groups**

| Variables | Turbine group (*n*=39) *n* (%) | Comparison group (*n*=158) *n** (%) |
|---|---|---|
| Sex | | |
| Male | 16 (41) | 63 (41) |
| Female | 23 (59) | 91 (58) |
| Age group, years | | |
| 18-20 | 1 (2.6) | 2 (1.2) |
| 21-30 | 1 (2.6) | 1 (0.5) |
| 31-40 | 5 (12.8) | 22 (13.9) |
| 41-50 | 10 (25.6) | 53 (33.5) |
| 51-60 | 11 (28.2) | 44 (27.8) |
| 61-70 | 7 (17.9) | 27 (17.1) |
| 71+ – | 3 (7.7) | 9 (5.6) |
| Education (completed) | | |
| High school | 11 (28.2) | 55 (34.8) |
| Polytechnic | 11 (28.2) | 48 (30.3) |
| University | 17 (43.6) | 54 (34.2) |
| Employment status | | |
| Full time | 21 (53.8) | 83 (52.5) |
| Part time | 0 (0) | 3 (1.8) |
| Unpaid work | 1 (2.6) | 3 (1.8) |
| Unemployed | 6 (15.3) | 27 (17.1) |
| Retired | 10 (25.6) | 40 (25.3) |
| Noise sensitivity | | |
| None | 13 (33.3) | 60 (37.9) |
| Moderate | 21 (55.3) | 76 (48.1) |
| Severe | 5 (12.8) | 20 (12.7) |
| Current illness | | |
| Yes | 10 (27) | 50 (31.6) |
| No | 27 (69.2) | 104 (65.8) |

*Totals may differ due to missing data

## Results

The response rates, 34% and 32% from the turbine and comparison groups, respectively, are typical for this type of research (e.g., van den Berg and colleagues[17] report a 37% response rate). Table 1 presents demographic information for the comparison and turbine groups. Prior to analyses the data were screened to identify potential confounds. The proportions of males and females in each area were equivalent ($\chi^2(1)$ = 0.001, $P$ = 0.967), while a Mann--Whitney U indicated no age difference between the two areas ($U(n_1 = 158, n_2 = 39)$ = 16022.5, $P$ = 0.802). Education ($\chi^2(2)$ = 2.474, $P$ = 0.291), noise sensitivity ($\chi^2(2)$ = 0.553, $P$ = 0.758), and self-reported illness ($\chi^2(1)$ = 0.414, $P$ = 0.562) were not associated with area.

Table 2 displays correlation coefficients (Pearson's *r*) between noise-related and health-related variables for both groups. Of remark is the negative correlation between annoyance and self-rated health for both groups, and a different pattern of correlations between noise sensitivity and annoyance across the two groups. Separate ANCOVA's revealed differences and similarities between the two areas in terms of HRQOL [Table 3]. Firstly, the turbine group reported a lower ($F(1,194)$ = 5.816 , $P$ = 0.017) mean physical HRQOL domain score than the comparison group. Scrutiny of the seven facets of the physical domain showed a difference in perceived sleep quality between the two areas ($t(195)$ = 3.089, $P$ = 0.006),

**Table 2: Pearson product-moment correlation coefficients (*r*) for noise-related and HRQOL variables. Statistics to the right of the major diagonal are for the comparison group, while those to the left are for the turbine group**

| | Sensitivity | Annoyance | Sleep | Health | Health-related quality of life | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Physical | Psychological | Social | Environment | Overall |
| Sensitivity | 1 | 0.134 | −0.017 | 0.082 | −0.017 | −0.069 | 0.006 | −0.066 | −0.109 |
| Annoyance | 0.440** | 1 | 0.042 | −0.258** | −0.209* | −0.135 | −0.155* | −0.319** | −0.097 |
| Sleep | −0.433** | −0.147 | 1 | 0.337** | 0.378** | 0.489** | 0.327** | 0.279** | 0.198* |
| Health | −0.234 | −0.308 | 0.471** | 1 | 0.706** | 0.493** | 0.158* | 0.284** | 0.327** |
| Physical§ | −0.24 | −0.212 | 0.364* | 0.524** | 1 | 0.655** | 0.29** | 0.455** | 0.475** |
| Psychological | −0.404* | −0.113 | 0.473** | 0.329* | 0.268 | 1 | 0.55** | 0.608** | 0.589** |
| Social | −0.359* | −0.236 | 0.116 | −0.021 | 0.036 | 0.212 | 1 | 0.456** | 0.457** |
| Environment | −0.235 | 0.028 | 0.404** | 0.2 | 0.474* | 0.468* | −0.17 | 1 | 0.546** |
| Overall | −0.203 | 0.16 | 0.471** | 0.289 | 0.282 | 0.286 | 0.162 | 0.380* | 1 |

*$P$ < 0.05, **$P$ < 0.001, §Item 16 (satisfaction with sleep) was removed from the Physical HRQOL domain when correlated with sleep satisfaction

**Table 3: Mean (M) and standard deviation (SD) statistics for the four HRQOL domains of the WHOQOL-BREF and amenity total scores, presented for both the comparison group and the turbine group**

| Measure | Turbine group | | Comparison group | |
|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* |
| Physical | 27.38 | 3.14 | 29.14 | 3.89 |
| Psychological | 22.36 | 2.67 | 23.29 | 2.91 |
| Social | 12.53 | 1.83 | 12.54 | 2.13 |
| Environmental | 29.92 | 3.76 | 32.76 | 4.41 |
| Amenity | 7.46 | 1.42 | 8.91 | 2.64 |

and between self-reported energy levels ($t(195)= 2.217$, $P = 0.028$). Secondly, the turbine group had lower ($F(1,194) = 5.694$ , $P = 0.018$) environmental QOL scores than the comparison group. This domain is the sum of eight items, and further analysis of these revealed that the turbine group considered their environment to be less healthy ($t(195)= 3.272$, $P < 0.007$) and were less satisfied with the conditions of their living space ($t(195)= 2.176$, $P = 0.031$). Thirdly, there were no statistical differences in social ($F(1,194) = 0.002$ , $P = 0.963$) or psychological ($F(1,194) = 3.334$, $P = 0.069$) HRQOL, although the latter was marginal and the mean for the turbine group was lower. Of the two generic WHOQOL-BREF items, the mean of the self-rated general health item was equivalent between turbine and comparison groups ($t(195) = 0.374$, $P = 0.709$), while the mean ratings for an overall quality of life item was lower ($t(195) = 2.364$, $P = 0.019$) in the turbine group.

The turbine group reported lower amenity than the comparison group ($F(1,194) = 18.88$, $P < 0.001$). There were no differences between groups for traffic ($t(195) = 0.568$, $P = 0.154$) or neighborhood ($t(195) = 1.458$, $P = 0.144$) noise annoyance. A comparison between ratings of turbine noise was not possible, but the mean annoyance rating for turbine group individuals who specifically identified wind turbine noise as annoying ($n$=23) was 4.59 (SD = 0.65), indicating that the turbine noise was perceived as extremely annoying. For the comparison group, seven "other" annoying noises were identified: barking dogs (x2), farm machinery (x2), and racing cars (x3).

## Discussion

Our results link exposure to wind turbines to degraded HRQOL, a finding that is consistent with the model described in Figure 1. Specifically, those residing in the immediate vicinity of a wind farm scored worse than a matched comparison group in terms of physical HRQOL and environmental QOL, and HRQOL in general. No differences were found in terms of psychological and social HRQOL, or in self-rated health. The high incidence of annoyance from turbine noise in the turbine group is consistent with the theory that exposure to wind turbine noise is the cause of these differences. Importantly, we also found a reduction in sleep satisfaction ratings, suggesting that both annoyance and sleep disruption may mediate the relationship between noise and HRQOL. These findings are consistent with those reported in relation to aviation noise[25] and traffic noise.[10,11]

Of further interest are the likely mechanisms involved in the degradation of HRQOL when exposed to turbine noise. Studies show that the level of turbine noise is a poor predictor of human response, and dose-response relationships typically explain little of the association between turbine noise and annoyance.[26] Pedersen *et al*.[4,26] and van den Berg *et al*.[15] show that, for equivalent noise levels, people judge wind turbine noise to be of greater annoyance than aircraft, road traffic, or railway noise. This may be due to the unique characteristics of turbine noise, that is, clusters of turbines present a cumulative effect characterized by a dynamic or modulating sound as turbines synchronise. The characteristic swishing or thumping noise associated with larger turbines[21] is audible over long distances, up to 5 km and beyond in some reports.[1]

van den Berg[17] showed that sound is the most annoying aspect of wind turbines, and is more of a problem at night. A large proportion (23/39) of respondents from the turbine group identified turbine noise as a problem and rated it to be extremely annoying. It should be noted that, in contemporary medicine, annoyance exists as a precise technical term describing a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration of health and well-being.[25] A Swedish study[26] reported that, for respondents who were annoyed by wind turbine noise, feelings of resignation, violation, strain, and fatigue were statistically greater than for respondents not annoyed by turbine noise. An attempt at constructing dose-response relationships between turbine noise level and annoyance in a European sample suggests that at calculated noise levels of 30-35 dB(A), 10% of the sample was rather or very annoyed at wind turbine sound, increasing to 20% at 35-40 dB(A) and 25% at 40-43 dB(A).[15]

We also observed lower sleep satisfaction in the turbine group than in the comparison group, a finding which is consistent with previous research.[2,4,17] One study directly related to wind turbine noise reported that 16% of respondents experiencing 35 dB(A) or more of noise suffered sleep disturbances due to turbine noise.[4] Another study investigating the effects of wind turbine noise on sleep showed that 36% of respondents who were annoyed at wind turbine noise also reported that they suffered disturbed sleep (versus 9% of those not annoyed).[15] A case-study approach examining exposure to turbine noise likewise identified turbine noise as an agent of sleep disturbance.[11] In relation to turbine noise levels, one study reported that even at the lowest noise levels (≈25 dB(A)), 20% of respondents reported disturbed sleep at least one night per month,[17] and that interrupted sleep and difficulty in returning to sleep increased with calculated noise level. Demonstrably, our data have also captured the effects of wind turbine noise on sleep, reinforcing previous studies suggesting that the acoustic characteristics of turbine noise are well suited to disturb the sleep of exposed individuals.

While strong correlations exist between the sound level and the perceived loudness of a sound, there is no clear relationship between level and the psychological responses that individuals have to a sound. Noise sensitivity is one psychological factor that is increasingly being related to noise annoyance in literature.[8] We found that, for the turbine group, noise sensitivity is a strong predictor of noise annoyance and is correlated with facets of HRQOL, supporting other studies suggesting that annoyance mediates the relationship between noise sensitivity and HRQOL.[25] Other studies show that noise sensitivity has a large impact on noise annoyance ratings, lowering annoyance thresholds by up to 10 dB.[8] The lack of statistical significance in the comparison group may indicate that, in the absence of annoying noise, the impact of noise sensitivity on HRQOL may be underestimated.

Another finding emerging from our data is that living close to wind turbines is associated with degraded amenity. This is consistent with previous research showing that wind turbine noise was judged incongruent with the natural soundscape of the area.[23] Amenity values are based upon what people feel about an area, its pleasantness, or some other value that makes it a desirable place to live. There is an expectation of "peace and quiet" when living in a rural area, and most choose to live in rural areas for this reason.[25] Furthermore, those who live in rural areas have different expectations about community noise than those living elsewhere.[4] Other studies[27,28] report that wind turbines are viewed as eyesores and visual spoilers of the environment, and from an aesthetic perspective, those who view the wind turbines as ugly are likely to disassociate them from the landscape and react more strongly to turbine noise. The measurement of the perceived visual impact of the wind farm was beyond the scope of the current study, specifically due to the masking of the study's intent. Scrutiny of the comments provided by the turbine group, however, revealed no mention of the impact of turbines on the landscape, reinforcing suggestions made by others,[5] that wind farm noise is more dominant than their visual aspects.

### Strengths and limitations

A strength of this study is the masking of the primary intent of the questionnaire by giving the impression that general neighborhood factors (e.g., street lighting, rubbish collection), and not wind turbine exposure, constituted the study's core aims. Concealing the study's objectives should reduce response bias, and our placing of the HRQOL items at the beginning of the survey, well before the three items probing noise annoyance, would serve to elicit subjective ratings of HRQOL without first being primed with potentially upsetting noise items. A further strength is the use of a nationally validated inventory that adopts a multidimensional approach to HRQOL.

The main limitation of the study, partly forced by our desire to conceal the aim of the survey, was that coincident noise measurements were not obtained. While independent estimates of wind farm noise in the Makara Valley have been reported,[21,22] it would have been desirable to undertake measurements in both the turbine and the control areas. That said, on the basis of the very few noise complaints made by those in the control areas (as described in the Results section), we are confident that the control areas provide typical semirural soundscapes that are not encroached by intrusive noise. An additional limitation of the study is the sample size of the turbine group. While the response rate compares favorably to other wind turbine research reported in the literature,[17] the sparsely populated locales surrounding wind farms in rural New Zealand presents a recruitment challenge. A larger sample of residents exposed to wind turbines would have afforded more analytical options. However, that the effects were found with such a modest sample size may be indicative of genuine differences between the two groups.

Any future adoption of the model presented in Figure 1 should increase the number of moderators, and include factors such as attitudes to the noise source and individual coping strategies. For example, the conflict between the Makara community and the wind farm developers could also potentially reduce HRQOL or amplify annoyance reactions and sleep difficulties. A telephone complaint line, set up by the wind farm developer as a condition of consent, attracted over 1000 noise complaints in the first year. Such conflict would induce stress and emotional reactions that would be expected to degrade psychological HRQOL, though this was not found to be different from the control group. An explanation of this null result on the psychological domain may be derived from the open-ended comments from the control group, which reveal that they themselves are in conflict with local governance bodies attempting to increase residential dwellings in the area.

## Conclusion

A thorough investigation of wind turbine noise and its effects on health is important given the prevalence of exposed individuals, a nontrivial number that is increasing with the popularity of wind energy.[29] For example, in the Netherlands it is reported that 440,000 inhabitants (2.5% of the population) are exposed to significant levels of wind turbine noise.[30] Additionally, policy makers are demanding more information on the possible link between wind turbines and health in order to inform setback distances. Our results suggest that utility-scale wind energy generation is not without adverse health impacts on nearby residents. Thus, nations undertaking large-scale deployment of wind turbines need to consider the impact of noise on the HRQOL of exposed individuals. Along with others,[31] we conclude that night-time wind turbine noise limits should be set conservatively to minimize harm, and, on the basis of our data, suggest that setback distances need to be greater than 2 km in hilly terrain.

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# Infrasound From Wind Turbines Could Affect Humans

**Alec N. Salt[1] and James A. Kaltenbach[2]**

**Abstract**

Wind turbines generate low-frequency sounds that affect the ear. The ear is superficially similar to a microphone, converting mechanical sound waves into electrical signals, but does this by complex physiologic processes. Serious misconceptions about low-frequency sound and the ear have resulted from a failure to consider in detail how the ear works. Although the cells that provide hearing are insensitive to infrasound, other sensory cells in the ear are much more sensitive, which can be demonstrated by electrical recordings. Responses to infrasound reach the brain through pathways that do not involve conscious hearing but instead may produce sensations of fullness, pressure or tinnitus, or have no sensation. Activation of subconscious pathways by infrasound could disturb sleep. Based on our current knowledge of how the ear works, it is quite possible that low-frequency sounds at the levels generated by wind turbines could affect those living nearby.

**Keywords**

cochlea, hair cells, A-weighting, wind turbine, Type II auditory afferent fibers

## Wind Turbines Generate Infrasound

The sounds generated by wind turbines vary widely, depending on many factors such as the design, size, rotor speed, generator loading, and different environmental conditions such as wind speed and turbulence (e.g., Jakobsen, 2005). Under some conditions, such as with a low wind speed and low generator loading, the sounds generated appear to be benign and are difficult to detect above other environmental sounds (Sonus, 2010).

But in many situations, the sound can contain a substantial low-frequency infrasound component. One study (Van den Berg, 2006) reported wind turbine sounds measured in front of a home 750 m from the nearest turbine of the Rhede wind farm consisting of Enercon E-66 1.8 MW turbines, 98 m hub height, and 35 m blade length. A second study (Jung & Cheung, 2008) reported sounds measured 148 to 296 m from a 1.5 MW turbine, 62 m hub height, 36 m blade length. In both these studies, which are among the few publications that report full-spectrum sound measurements of wind turbines, the sound spectrum was dominated by frequencies below 10 Hz, with levels of over 90 dB SPL near 1 Hz.

The infrasound component of wind turbine noise is demonstrated in recordings of the sound in a home with GE 1.5 MW wind turbines 1,500 ft downwind as shown in Figure 1. This 20-second recording was made with a microphone capable of recording low-frequency components. The sound level over the recording period, from which this excerpt was taken, varied from 28 to 43 dBA. The audible and inaudible (infrasound) components of the sound are demonstrated by filtering the waveform above 20 Hz (left) or below 20 Hz (right). In the audible, high-pass filtered waveform, the periodic "swoosh" of the blade is apparent to a varying degree with time. It is apparent from the low-pass filtered waveform that the largest peaks in the original recording represent inaudible infrasound. Even though the amplitude of the infrasound waveform is substantially larger than that of the audible component, this waveform is inaudible when played by a computer's sound system. This is because conventional speakers are not capable of generating such low frequencies and even if they could, those frequencies are typically inaudible to all but the most sensitive unless played at very high levels. It was also notable in the recordings that the periods of high infrasound level do not coincide with those times when the audible component is high.

This shows that it is impossible to judge the level of infrasound present based on the audible component of the sound. Just because the audible component is loud does not mean that high levels of infrasound are present. These measurements show that wind turbine sounds recorded inside a home can contain a prominent infrasound component.

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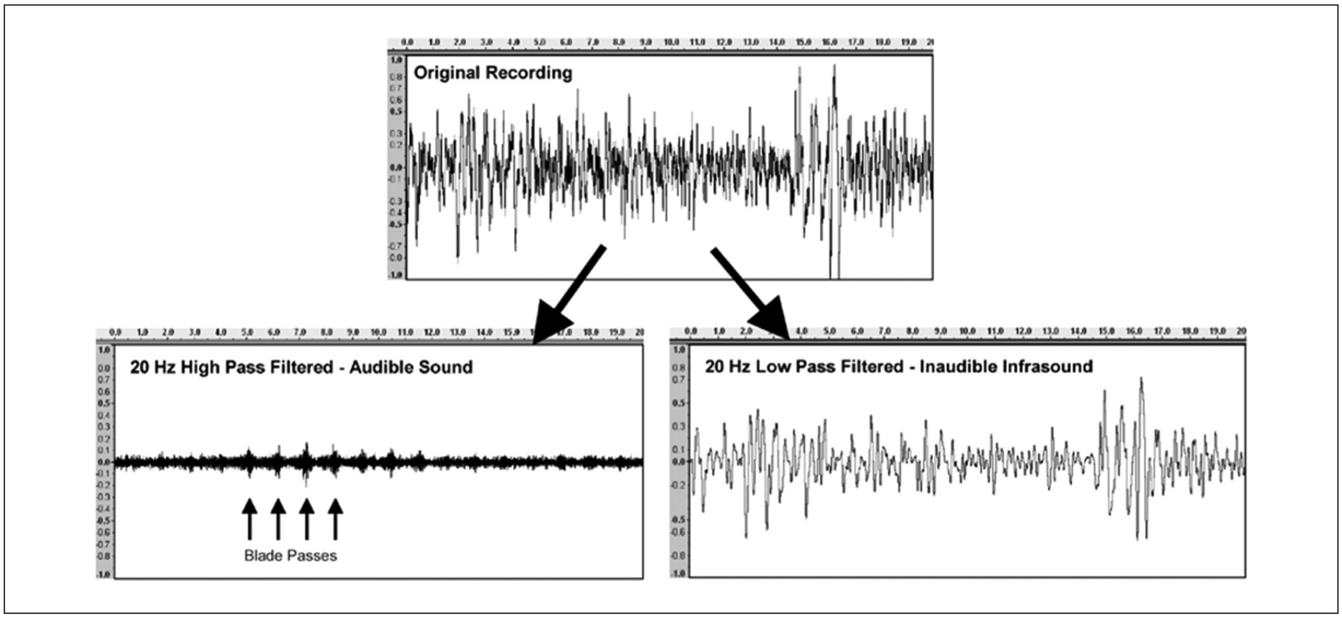


**Figure 1.** *Upper Panel:* Full-spectrum recording of sound from a wind turbine recorded for 20 seconds in a home with the wind turbine 1,500 ft downwind (digital recording kindly provided by Richard James). *Lower Left Panel:* Result of high-pass filtering the waveform at 20 Hz, showing the sound that is heard, including the sounds of blade passes. *Lower Right Panel:* Result of low-pass filtering the waveform at 20 Hz, showing the infrasound component of the sound

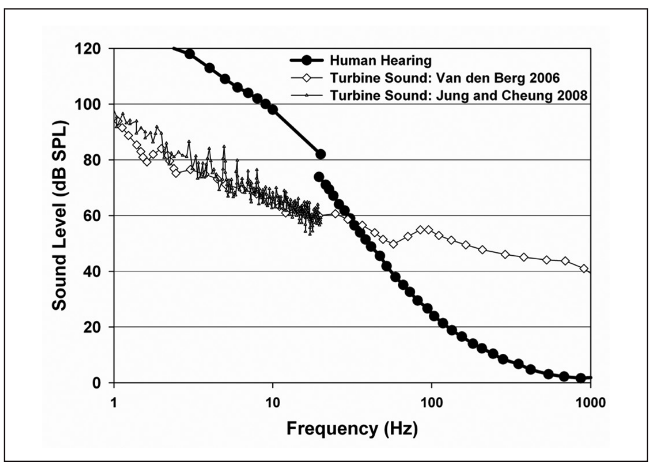


**Figure 2.** Wide band spectra of wind turbine sounds (Jung & Cheung, 2008; Van den Berg, 2006) compared with the sensitivity of human hearing (International Organization for Standardization, 2003, above 20 Hz; Møller & Pederson, 2004, below 20 Hz). The levels of sounds above 30 Hz are above the audibility curve and would be heard. Below 30 Hz, levels are below the audibility curve so these components would not be heard

## Wind Turbine Infrasound Is Typically Inaudible

Hearing is very insensitive to low-frequency sounds, including those generated by wind turbines. Figure 2 shows examples of wind turbine sound spectra compared with the sensitivity of human hearing. In this example, the turbine sound components above approximately 30 Hz are above threshold and therefore audible. The sounds below 30 Hz, even though they are of higher level, are below the threshold of audibility and therefore may not be heard. Based on this comparison, for years it has been assumed that the infrasound from wind turbines is not significant to humans. Leventhall (2006) concluded that "infrasound from wind turbines is below the audible threshold and of no consequence." (p.34) Leventhall (2007) further stated that "if you cannot hear a sound you cannot perceive it in other ways and it does not affect you." (p.135)

Renewable UK (2011), the website of the British Wind Energy Association, quotes Dr. Leventhall as stating, "I can state quite categorically that there is no significant infrasound from current designs of wind turbines." Thus, the fact that hearing is insensitive to infrasound is used to exclude the possibility that the infrasound can have any influence on humans. This has been known for many years in the form of the statement, "What you can't hear can't affect you." The problem with this concept is that the sensitivity of "hearing" is assumed to equate with sensitivity of "the ear." So if you cannot hear a sound then it is assumed that the sound is insufficient to stimulate the ear. Our present knowledge of the physiology of the ear suggests that this logic is incorrect.

## The Ear Is Sensitive to Wind Turbine Infrasound

The sensory cells responsible for hearing are contained in a structure in the cochlea (the auditory portion of the inner ear) called the organ of Corti. This organ runs the entire length of the cochlear spiral and contains two types of sensory cells, which have completely different properties. There is one row

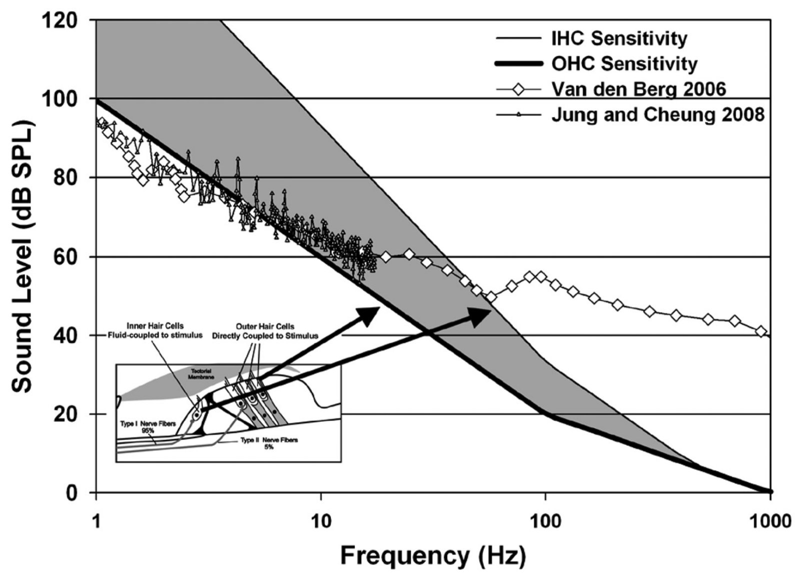


**Figure 3.** The thin line shows the estimated sensitivity of inner hair cells (IHC) as a function of frequency, which is comparable with the human audibility curve shown in Figure 2 and which is consistent with hearing being mediated by the IHC (based on Cheatham & Dallos, 2001). The thick line shows the estimated sensitivity of the outer hair cells (OHC), which are substantially more sensitive than the IHC. Sound components of the overlaid wind turbine spectra within the shaded region (approximately 5 to 50 Hz) are too low to stimulate the IHC and cannot therefore be heard but are of sufficient level to stimulate the OHC. The inset shows a cross section of the sensory organ of the cochlea (the organ of Corti) showing the locations of the IHC and OHC

of sensory inner hair cells (IHC) and three rows of outer hair cells (OHC) as shown schematically in the inset to Figure 3. For both IHC and OHC, sound-induced deflections of the cell's sensory hairs provide stimulation and elicit electrical responses. Each IHC is innervated by multiple nerve fibers that transmit information to the brain, and it is widely accepted that hearing occurs through the IHC. The rapidly declining sensitivity of hearing at lower frequencies (Figure 2) is accounted for by three processes that selectively reduce low-frequency sensitivity (Cheatham & Dallos, 2001), specifically the properties of middle ear mechanics, from pressure shunting through the cochlear helicotrema and from "fluid coupling" of the inner hair cell stereocilia to the stimulus (reviewed in detail by Salt & Hullar, 2010).

The combined effect of these processes, quantified by Cheatham and Dallos (2001), are shown as the "IHC sensitivity" curve in Figure 3. The last component attenuating low frequencies, the so-called fluid coupling of input, arises because the sensory hairs of the IHC do not contact the overlying gelatinous tectorial membrane but are located in the fluid space below the membrane.

As a result, measurements from the IHC show that they do not respond to sound-induced displacements of the structure but instead their amplitude and phase characteristics are consistent with them responding to the velocity of the stimulus. As stimulus frequency is lowered, the longer cycles result in lower stimulus velocity, so the effective stimulus falls by 6 dB/octave. This accounts for the known insensitivity of the IHC to low-frequency stimuli. For low frequencies, the calculated sensitivity of IHC (Figure 3) compares well with measures of hearing sensitivity (Figure 2), supporting the view that hearing is mediated by the IHC.

The problem, however, arises from the more numerous OHC of the sensory organ of Corti of the ear. Anatomic studies show that the sensory hairs of the OHC are embedded in the overlying tectorial membrane, and electrical measurements from these cells show their responses depend on the displacement rather than the velocity of the structure. As a result, their responses do not decline to the same degree as IHC as frequency is lowered.

Their calculated sensitivity is shown as the "OHC sensitivity" curve in Figure 3. It is important to note that the difference between IHC and OHC responses has nothing to do with frequency-dependent effects of the middle ear or of the helicotrema (the other two of the three components mentioned above). For example, any attenuation of low-frequency stimuli provided by the helicotrema will equally affect both the IHC and the OHC. So the difference in sensitivity shown in Figure 3 arises purely from the difference in how the sensory hairs of the IHC and OHC are coupled to the overlying tectorial membrane.

The important consequence of this physiological difference between the IHC and the OHC is that the OHC are stimulated at much lower levels than the IHC. In Figure 3, the portion of the wind turbine sound spectrum within the shaded region represents frequencies and levels that are too low to be heard, but which are sufficient to stimulate the OHC of the ear.

This is not confined to infrasonic frequencies (below 20 Hz), but in this example includes sounds over the range from 5 to 50 Hz. It is apparent that the concept that "sounds you can't hear cannot affect you" cannot be correct because it does not recognize these well-documented physiologic properties of the sensory cells of the inner ear.

Stimulation of OHC at inaudible, low levels can have potentially numerous consequences. In animals, cochlear microphonics demonstrating the responses of the OHC can be recorded to infrasonic frequencies (5 Hz) at levels as low as 40 dB SPL (Salt & Lichtenhan, in press). The OHCs are innervated by Type II nerve fibers that constitute 5% to 10% of the auditory nerve fibers, which connect the hair cells to the brainstem. The other 90% to 95% come from the IHCs. Both Type I (from IHC) and Type II (from OHC) nerve fibers terminate in the cochlear nucleus of the brainstem, but the anatomical connections of the two systems increasingly appear to be quite different. Type I fibers terminate on the main output neurons of the cochlear nucleus. For example, in the dorsal part of the cochlear nucleus, Type I fibers connect with fusiform cells, which directly process information received from the ear and then deliver it to higher levels of the auditory pathway. In contrast, Type II fibers terminate in the granule cell regions of the cochlear nucleus (Brown, Berglund, Kiang, & Ryugo, 1988). Some granule cells receive direct input from Type II fibers (Berglund & Brown, 1994). This is potentially significant because the granule cells provide a major source of input to nearby cells, whose function is inhibitory to the fusiform cells that are processing heard sounds. If Type II fibers excite granule cells, their ultimate effect would be to diminish responses of fusiform cells to sound. Evidence is mounting that loss of or even just overstimulation of OHCs may lead to major disturbances in the balance of excitatory and inhibitory influences in the dorsal cochlear nucleus. One product of this disturbance is the emergence of hyperactivity, which is widely believed to contribute to the perception of phantom sounds or tinnitus (Kaltenbach et al., 2002; Kaltenbach & Godfrey, 2008). The granule cell system also connects to numerous auditory and nonauditory centers of the brain (Shore, 2005). Some of these centers are directly involved in audition, but others serve functions as diverse as attentional control, arousal, startle, the sense of balance, and the monitoring of head and ear position (Godfrey et al., 1997).

Functions that have been attributed to the dorsal cochlear nucleus thus include sound localization, cancellation of self-generated noise, orienting the head and ears to sound sources, and attentional gating (Kaltenbach, 2006; Oertel & Young, 2004). Thus, any input from OHCs to the circuitry of the dorsal cochlear nucleus could influence functions at several levels.

## A-Weighted Wind Turbine Sound Measurements

Measurements of sound levels generated by wind turbines presented by the wind industry are almost exclusively A-weighted and expressed as dBA. When measured in this manner, the sound levels near turbines are typically in the range of 30 to 50 dBA, making wind turbine sounds,

> about the same level as noise from a flowing stream about 50-100 meters away or the noise of leaves rustling in a gentle breeze. This is similar to the sound level inside a typical living room with a gas fire switched on, or the reading room of a library or in an unoccupied, quiet, air-conditioned office. (Renewable UK, 2011)

On the basis of such measurements, we would expect wind turbines to be very quiet machines that would be unlikely to disturb anyone to a significant degree. In contrast, the human perception of wind turbine noise is considerably different. Pedersen and Persson-Waye (2004) reported that for many other types of noise (road traffic, aircraft, railway), the level required to cause annoyance in 30% of people was over 70 dBA, whereas wind turbine noise caused annoyance of 30% of people at a far lower level, at around 40 dBA. This major discrepancy is probably a consequence of A-weighting the wind turbine sound measurements, thereby excluding the low-frequency components that contribute to annoyance. A-weighting corrects sound measurements according to human hearing sensitivity (based on the 40 phon sensitivity curve). The result is that low-frequency sound components are dramatically deemphasized in the measurement, based on the rationale that these components are less easily heard by humans. An example showing the effect of A-weighting the turbine sound spectrum data of Van den Berg (2006) is shown in Figure 4. The low-frequency components of the original spectrum, which resulted in a peak level of 93 dB SPL at 1 Hz, are removed by A-weighting, leaving a spectrum with a peak level of 42 dBA near 1 kHz. A-weighting is perfectly acceptable if hearing the sound is the important factor. A problem arises though when A-weighted measurements or spectra are used to assess whether the wind turbine sound affects the ear. We have shown above that some components of the inner ear, specifically the OHC, are far more sensitive to low-frequency sounds than is hearing. Therefore, A-weighted sounds do not give a valid representation of whether wind turbine noise affects the ear or other aspects of human physiology mediated by the OHC and unrelated to hearing. From Figure 3, we know that sound frequencies down to 3 to 4 Hz may be stimulating the OHC, yet the A-weighted spectrum in Figure 4 cuts off all components below approximately 14 Hz. For this reason, the determination of whether wind turbine sounds affect people simply cannot be made based on A-weighted sound measurements. A-weighted measurements are inappropriate for this purpose and give a misleading representation of whether the sound affects the ear.

Alternatives to A-weighting are the use of full-spectrum (unweighted), C-weighted, or G-weighted measurements. G-weighted measurements use a weighting curve based on the human audibility curve below 20 Hz and a steep cutoff above 20 Hz so that the normal audible range of frequencies is deemphasized. Although the shape of this function is arbitrary

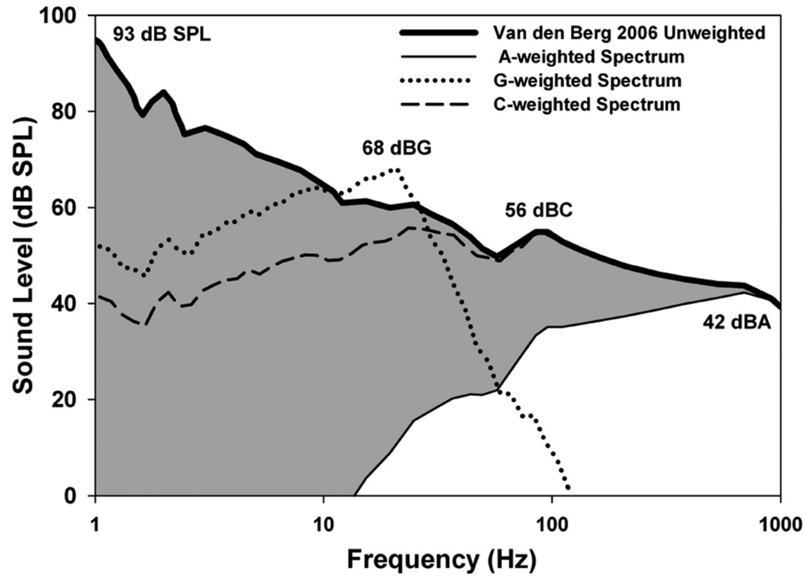


**Figure 4.** Low-frequency components of wind turbine sound spectrum (below 1 kHz) before and after A-weighting. The original spectrum was taken from Van den Berg (2006). The shaded area represents the degree of alteration of the spectrum by A-weighting. A weighting (i.e., adjusting the spectrum according to the sensitivity of human hearing) has the effect of ignoring the fact that low-frequency sounds can stimulate the OHC at levels that are not heard. Representing this sound as 42 dBA, based on the peak of the spectrum, ignores the possibility that low-frequency components down to frequencies as low as 5 Hz (from Figure 3) are stimulating the OHC. Also shown are the spectra after G-weighting (dotted) and C-weighting (dashed) for comparison

when hearing is not the primary issue, it does give a measure of the infrasound content of the sound that is independent of higher frequency, audible components, as shown in Figure 4. By applying the function to the normal human hearing sensitivity curve, it can be shown that sounds of approximately 95 dBG will be heard by humans, which agrees with observations by Van den Berg (2006). Similarly, by G-weighting the OHC sensitivity function in Figure 3, it can be estimated that sound levels of 60 dBG will stimulate the OHC of the human ear. In a survey of infrasound levels produced by wind turbines measured in dBG (Jakobsen, 2005), upwind turbines typically generated infrasound of 60 to 70 dBG, although levels above and below this range were observed in this and other studies. From Jakobsen's G-weighted measurements, we conclude that the level of infrasound produced by wind turbines is of too low a level to be heard, but in most cases is sufficient to cause stimulation of the OHC of the human ear. C-weighting also provides more representation of low-frequency sound components but still arbitrarily de-emphasizes infrasound components.

## Is the Infrasound From Wind Turbines Harmful to Humans Living Nearby?

Our present understanding of inner ear physiology and of the nature of wind turbine sounds demonstrates that low-level infrasound produced by wind turbines is transduced by the OHC of the ear and this information is transmitted to the cochlear nucleus of the brain via Type II afferent fibers. We therefore conclude that dismissive statements such as "there is no significant infrasound from current designs of wind turbines" are undoubtedly false. The fact that infrasound-dependent information, at levels that are not consciously heard, is present at the level of the brainstem provides a scientific basis for the possibility that such sounds can have influence on people. The possibility that low-frequency components of the sound could contribute both to high annoyance levels and possibly to other problems that people report as a result of exposure to wind turbine noise cannot therefore be dismissed out of hand.

Nevertheless, the issue of whether wind turbine sounds can cause harm is more complex. In contrast to other sounds, such as loud sounds, which are harmful and damage the internal structure of the inner ear, there is no evidence that low-level infrasound causes this type of direct damage to the ear. So infrasound from wind turbines is unlikely to be harmful in the same way as high-level audible sounds.

The critical issue is that if the sound is detected, then can it have other detrimental effects on a person to a degree that constitutes harm? A major complicating factor in considering this issue is the typical exposure duration. Individuals living near wind turbines may be exposed to the turbine's sounds for prolonged periods, 24 hours a day, 7 days a week for weeks, possibly extending to years, although the sound level will vary over time with varying wind conditions. Although there have been many studies of infrasound on humans, these have typically involved higher levels for limited periods (typically of up to 24 hours). In a search of the literature, no studies were found that have come close to replicating the long-term exposures to low-level infrasound experienced by those living near wind turbines. So, to date, there are no published studies showing that such prolonged exposures do not harm humans. On the other hand, there are now numerous reports (e.g., Pierpont, 2009; Punch, James, & Pabst, 2010), discussed extensively in this journal, that are highly suggestive that individuals living near wind turbines are made ill, with a plethora of symptoms that commonly include chronic sleep disturbance. The fact that such reports are being dismissed on the grounds that the level of infrasound produced by wind turbines is at too low a level to be heard appears to totally ignore the known physiology of the ear. Pathways from the OHC to the brain exist by which infrasound that cannot be heard could influence function. So, in contrast, from our perspective, there is ample evidence to support the view that infrasound could affect people, and which justifies the need for more detailed scientific studies of the problem. Thus, it is possible that people's health could suffer when turbines are placed too close to their homes and this becomes more probable if sleep is disturbed by the infrasound. Understanding these phenomena may be important to deal with other sources of low-frequency noise and may establish why some individuals are more sensitive than others. A better understanding may also allow effective procedures to be implemented to mitigate the problem.

We can conclude that based on well-documented knowledge of the physiology of the ear and its connections to the brain, it is scientifically possible that infrasound from wind turbines could affect people living nearby.

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## Bios

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# Low Frequency Noise and Infrasound

**(Some possible causes and effects upon land-based animals and freshwater creatures)**

A literary comment
By
Ivan Buxton
2006

# INDEX

**SUMMARY**
The adverse effects of low frequency noise (LFN) and infrasound are generally understood although not widely appreciated because by and large, up until recently most creatures do not encounter them for long periods of time or at levels that are perceived to be dangerously low.

Furthermore, general observations of the effects of these types of sound in respect of land-based creatures other than humans are largely conspicuous by their absence. There also appears to be a dearth of information relative to those inhabiting freshwater.

Which might presuppose that LFN including infrasound poses them little or no problem. Such a premise cannot be discounted but until explored seems to leave a knowledge gap that could be significant. This literary report has combined a variety of study findings and concludes there is a case to answer when land based animals and freshwater creatures are exposed to noise at low Hz levels.

Because of the limitations of our hearing it would be easy to suppose that noises beyond our receiving range do not exist and should therefore be of no concern to us. Yet both very high and extremely low inaudible sounds may be harmful to us and other animals with similar but not identical ranges of hearing.

Different people perceive sounds differently and much depends upon the individual levels of tolerance and what to them constitutes disturbance. Other creatures have lower acceptance levels, as their survival is more reliant upon instinct and interpretation of unusual sounds as a source of danger.

Human acceptance of unwanted sound is subject to the test of reasonability where each case of complaint is considered upon its own merit. Measurement criteria help assess levels at which hearing damage may ensue or a nuisance is established.

With other animals the threshold of reasonability can only commence with human standards applied judgementally to each creature and the environment in which it thrives, this in itself may be unreasonable.

To gauge effect of LFN and infrasound upon land based and freshwater creatures then concentration should be focussed upon intensity and frequency as much as upon speed of travel. Sound travels faster in a mass of greater density than air. Therefore a greater pressure level is also delivered suggesting a perturbing situation might exist for both freshwater dwellers and land based creatures diving under freshwater water in close proximity to sound sources emitting high intensity LFN over long periods of time.

Sources of infrasound and LFN are many and varied with constant new additions. Some are controversial for reasons including noise emissions. Wind turbine generators were raised as a noise concern some years ago. Yet only recently have reports been released by the wind industry with results of desktop studies and none seem to have been conducted on wild animals at wind farms.

A UK press release in 2005 suggested blame for the death of baby seals was due to mother seals aborting their pups through disturbance from pile driving for foundations for off shore wind turbines. Elsewhere some studies have shown that sea mammals, fish, birds and animals exposed to excessive LFN and infrasound has caused them harm.

The hearing abilities of creatures other than man are difficult to determine. Even with sea mammals where studies have been concentrated because of fears surrounding noise created by human activities, only relatively little research exists into the range of hearing.

Whales, dolphins and porpoise have all shown signs of distress from exposure to varying levels of noise at low frequencies and from a variety of sources. Research has shown fish ears are damaged by noise from repeated use of under water air guns and behavioural studies determined the fish became disoriented and consequently were vulnerable.

There are a great number of articles that include reference to the effects of infrasound upon humans. The frequency ranges are recorded in many of these and the overall result always appears to depend upon the exposure time when coupled with the dB and Hz levels.

A few seconds is all it takes at very low Hz and high dB levels before severe problems arise. Even at a level of dB normally found comfortable for listening to music for example, if the Hz level is low then a significant adverse reaction has been reported.

There is reason to suppose that similar effects would also occur with wild animals if exposed to the sounds for long enough periods. The presumption must be that as soon as they felt uncomfortable they would move away from the zone of discomfort. A term more properly described as, disturbance and displacement, which in the case of protected species would be contrary to appropriate legislation.

The concerns of the effects of infrasound are clearly real whether they are upon humans, marine life or land based and freshwater creatures and in extreme cases the results of high levels of exposure could be lethal. Even relatively low levels can be debilitating and create disturbance.

Laboratory studies upon animals have been reviewed with quite chilling results, as it clear that deformities, damage and impairment occur to the subjects with regularity. Admittedly the animals were contained and subjected to exposure times of several hours per day at moderate to high intensity levels of LFN and infrasound. Yet fish and aquatic creatures contained in ponds and lakes would certainly be unable to escape whatever the level of sound intensity or duration of exposure.

Other experiments signify that indirect consequences can arise from exposure to LFN due to the masking effect. Sounds from wind turbines are believed to have disguised the danger of rotating blades and caused the death of large numbers of birds. A report concluded that birds probably couldn't hear the noise of the blades as well as humans can and would be unable to see them because of motion smear.

Constant road noise raises the ambient levels and could affect creatures because of the masking effect. Less frequent but regular sounds might create just enough habituation as to be dangerous and occasionally (such as in country lanes) lull creatures from hiding at lethal moments.

Estimates have been made that bird song will attenuate at the rate of 5dB per metre for a bird 10metres above ground level in an open field to 20dB per metre for a bird on the ground in a coniferous forest. Therefore any high volume of noise of a virtually permanent rate, such as continuous nearby traffic flow could mask communication attempts.

Studies have been made of the effects of noise upon some bird species and quite clearly low frequency noise played a significant role in creating bird disturbance/displacement and was sufficient to cause serious reduction in breeding numbers in the study areas.

Vocal communication plays an important part in the social interaction of many creatures and the imposition of noise from man-made sources could potentially disrupt the ability of species to communicate or it might introduce new and possibly disturbing behavioural factors into social groups.

Aircraft noise and sonic booms have been blamed for reduction in egg laying by domestic poultry. The use of military aircraft at supersonic speeds resulted in some successful claims for damages following alleged injury or loss involving livestock.

Goats have been adversely affected by exposure to jet noise resulting in reduced milk yields. Pigs suffered excessive hormonal secretion as well as water and sodium retention after being subjected to continuous noise over several days.

Wild mice captured from a field at the end of an airport runway were compared with mice from a rural field not exposed to high levels of aircraft sounds and noise was concluded to be the dominant stressful factor causing adrenal weight differences.

Mobile telephone masts emit signals of a low frequency nature and operate in pulses.  House sparrows have declined in urban areas where technology producing low frequency noise and infrasound has increased in tandem with the decline.  Mayhap there is a causal link.

Recorded noise from a miscellany of sources including machinery, military hardware, electrical and diesel engines, roller coasters and many others have been used in experiments upon sheep and lambs and the results have shown increased heart rates, respiratory changes and reduction in feeding.

Anthropological sources of LFN and infrasound are increasing and will continue so to do.  There is clearly a cause for concern because of the likely effects upon wildlife and current protective measures seem inadequate.

Thus it is recommended that better environmental assessments be made to accompany all planning applications involving erection or construction of plant, machinery, buildings, infrastructure or other potential sources of low frequency noise and infrasound, irrespective of project size.

The measurement methods should be reviewed to embrace ‘C’ Weighting and ‘G’ Weighting as well as the usual ‘A’ Weighting so that a proper appreciation of the extent of LFN and infrasound is achieved before, during and after the noise source is installed.

Moreover, regarding larger sites continuous wildlife monitoring and reporting should be in place with conditions attached to planning consents that an order for immediate cessation of the noise source can be made without the need for further deliberation if found detrimental to creature well being.

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**INTRODUCTION**

Despite a plethora of articles reporting the apparent results of low frequency and infrasound upon certain forms of marine wildlife, no studies seem currently available in respect of the impact of this type of noise upon wild land based and fresh-water creatures and whether it be might be harmful.

A vast range of tests, reports and speculation spanning the sublime to the ridiculous covers research into low frequency and infrasound plus the possible, probable and actual distress caused to some sea creatures as well as humans.

Yet a wealth of other creatures relies on their sense of hearing and indubitably is exposed to and experience low frequency noises. In the case of those living in the wild, good hearing is quite simply a survival aid.

Even some invertebrates without conventional auditory receptors register vibrations and use them for either communication or as warnings. The acoustical energy that many invertebrates can sense allows them to survive.

Creatures have evolved senses including those of hearing for reasons of assisting in procreation, communication and protection. The latter includes defence from the danger of predation or to enable them to find food.

Apart from some species of marine and land mammals, the need by other creatures to harness and utilise infrasound for their own benefit has not apparently been of importance. Neither has the requirement to identify and avoid infrasound been particularly necessary. This may explain why the ecological process has not generally equipped them with hearing ranges to detect such low levels of noise.

Inhabiting the land, sea and air in tandem with humans may have changed the situation. Shipping emits low frequency sound, as do lorries, aeroplanes and wind turbines. For many species it has become increasingly difficult to survive especially those prone to disturbance or reliant upon prey driven out by human encroachment.

Quite what detrimental effects are caused by sounds below the hearing threshold of creatures that hitherto have had no need to detect them is open to conjecture. After all does it matter for example; that a rabbit cannot hear a sound from something, provided it is not going to be eaten by whatever emits it?

We know from concerns by environmentalists studying marine mammals that the increasing output of very low levels of sound waves from anthropological sources can cause them to suffer. Could similar noise be unwittingly affecting animals, fish and other creatures on land and in fresh-water?

The adverse effects of low frequency and infrasound are generally understood although not widely appreciated because by and large, up until recently most creatures do not encounter them for long periods of time or at levels that are perceived to be dangerously low.

Could the appreciation of danger change as the regularity of exposure increases? We already know that roads, railways, housing, factories, agriculture and airports are just some of the sources of disturbance causing creatures to retreat and die from the development of the human race.

The inventiveness of mankind continually creates new technology often at the expense of other species either directly or indirectly. There are innumerable instances of pollution from human errors many resulting from the introduction of technological products.

Sometimes belated steps are taken to try and rectify or reduce the damage and perhaps eradicate the causes. Lead free petrol and restriction of CFC gases are quite recent examples but it usually takes a long time before the problem is identified, longer for remedial action and longer still for it to be effective.

The topic of so-called global warming is currently occupying a great deal of political, commercial and scientific time. The acceleration of climate change is generally accepted to have been induced by human activities and is seen by some as the largest current threat to all living creatures.

Consequently it seems further technology must be applied to try and combat what is considered one of the main causes of the situation, the emission of noxious substances from the use of fossil fuels. But is a possible calamity being replaced by a probable disaster?

Both land and sea are being littered with wind turbines, some of which are very big pieces of equipment. These machines are being ‘sold’ to the public as a panacea because they harness a renewable and natural resource (wind) and seemingly allow production of energy without any significant levels of pollution.

Emphasis is placed upon the amount of carbon dioxide and other emissions they prevent from being generated when similar levels of energy are secured from the conventional sources burning fossil fuels.

Promoting the positive aspects of energy generated from wind power is to be expected but there are also negative issues. One of which is seen as the creation of low frequency noise as the turbines labour to produce a satisfactory end product.

Wind turbines make a noise. This is inevitable but it is the type and level of noise that has to be considered. Understandably most concern has been shown over the effects that these large generators have upon humans and to a lesser extent birds and bats.

Initially with the early and smaller type of turbines very little notice was taken of any low frequency sound they might have produced. More concern was shown over higher frequency noise leading to design modification and to a limited extent more care over choice of sites.

Now with the substantial increase in size and number of these machines infrasound has begun to be considered as a possible problem. Reports of people suffering in strange ways from hitherto undiagnosed complaints following the erection of turbines relatively close to their homes meant there was a real cause for concern.

This has lead to the production of a series of reports analysing the probable level of infrasound made by this machinery on land and what effects prolonged exposure would or would not have on humans. This proliferation of research has not specifically mentioned the effects this type of noise could have on other species. Yet other creatures have ears and nervous systems.

In the UK attention has been given to the turbines with foundations on land elsewhere those erected in the sea have also been considered as problematical. Seawater is a better conductor of sound and contains species particularly vulnerable to the projection of low frequency noise.

Land based turbines however, may be placed within the vicinity of fresh-water, which also conducts sound more efficiently than the earth. Seemingly however this has escaped comment in the reports published in response to the concerns over any impact of low frequency sounds.

Furthermore, general observations of the effects of these types of sound in respect of land-based creatures other than humans are largely conspicuous by their absence. There also appears to be a dearth of information relative to those inhabiting fresh-water. This might presuppose infrasound poses them little or no problem.

Such a premise cannot be discounted but until explored seems to leave a knowledge gap that could be significant. A phrase often quoted is that the absence of evidence is not the evidence of absence.

Apparently therefore, a need arises to initially garner information of possible relevancy and attempt to correlate and assimilate facts that could be applied, to amongst other living things, land-based fauna and fresh-water fishes.

Accredited publications, desktop information, established scientific data; practical field studies and in depth analysis of enquiry into the causes and effects upon specific wild land mammals of Great Britain for example, are simply not available to call upon.

Conducting practical tests upon live wild animals in their natural environment is the obvious method of establishing what if any distress would be caused by partial or prolonged exposure to low frequency noises.

This form of experimentation has both ethical and practical drawbacks and should be considered the instance of last resort. Some work however, has been done on domestic cats and dogs without unduly exposing them to dangerous levels of infrasound and the results may be of interest.

Infrasound studies have also been conducted as laboratory experiments upon rats and guinea pigs with some rather disturbing results. Exposure at quite low Hz levels and moderately high intensity caused significant changes to vital organs.

Perhaps measurements and observation at sites containing large wind turbines might allow the opportunity for scientific study. Unfortunately without a full species count before installation of the machines it would be difficult to assess if noise of any type let alone that emergent from low frequency sound or infrasound had been adversely effective.

Discussion with turbine manufacturers might be beneficial for securing particulars of anticipated noise emission levels, as the machinery they produce should have to undergo rigorous safety tests. Existing data on sounds measured at wind farms with onsite emission levels may be available and would be helpful.

Consequently analysis of this knowledge and of acoustic technology generally plus the findings of accomplished persona who have already commented upon low frequency and infrasound in a variety of ways is a logical starting point.

The ostensible lack of data other than that relative to specific effects upon non-marine creatures or humans could at first glance be considered as a hindrance preventing informed comment upon the subject.

Conversely a second look could show a beckoning blank canvas and such a standpoint is an irresistible lure.

In essence the comments made in the following pages are not scientific other than where they are founded upon proven formulae or text book knowledge and may at times be considered subjective.

I believe they are based upon common sense and hopefully may open the lid covering a topic ripe for detailed research. For without it the consequences upon our unsuspecting natural fauna may be intolerable.

I hope the challenge is compelling.

## WHAT IS INFRASOUND?

A dictionary definition is, 'having a frequency below that of sound'.

Consequently in order to define infrasound in an easily perceived manner we must first understand the meaning of sound and that, if you forgive the phrase, is not as simple as it sounds!

One reason for the lack of simplicity is the complexity of what we actually hear and how the listener distinguishes this at the moment it is heard.

Another is the astonishing diversity of sounds or noises that are constantly with us. The background is never really silent as some level of sound is always present. This is called the ambient sound.

Our ears and those of other animals are amazing pieces of technology. The intricacy of components that make up an ear and how it receives and interprets sound have intrigued generations of scientists.

The human ear contains structures essential for both the sense of hearing and sense of balance. The eighth cranial nerve (made up of the auditory and vestibular nerves) carries nerve impulses for hearing and balance to the brain.

As our ears serve a dual-purpose, damage to either hearing or balance can be painful, dangerous, debilitating or downright unpleasant.

Sound waves cause the tympanic membrane (eardrum) to vibrate. The three bones in the ear (malleus, incus and stapes) pass these vibrations on to the cochlea. The cochlea is a snail shaped, fluid filled structure in the inner ear. Inside the cochlea is the organ of Corti.

Hair cells are located on the basilar membrane of the cochlea. The hair (cilia) of the hair cells makes contact with another membrane called the tectorial membrane. When the hair cells are excited by vibration a nerve impulse is generated in the auditory nerve. These impulses are sent to the brain.

New sources of sound are being continually produced and some of the sounds themselves are also perceived as new, although in most cases will simply be a variation of an old theme. Rather like music where a collection of the same notes placed in differing orders produces a range of sounds, some pleasant and others awful.

Which is the best or worst arrangement may well depend upon an individual's perception of the 'tune'. Generally the more melodic the more widely spread is the agreement, but what if the sound cannot be heard?

Because of the limitations of our hearing it would be easy to suppose that noises beyond our receiving range do not exist and should therefore be of no concern to us. Yet both very high and extremely low inaudible sounds may be harmful to us and other animals with similar but not identical ranges of hearing.

Some sounds will have occurred previously and gone unreported or unnoticed but the problems of the effects of noise have increased and by far the most problematic are those caused or created by human actions.

In many instances noise has become intolerable and legislation has been necessary to protect human health. No law deals with the specific effects of noise upon other creatures although Acts of Parliament and International Conventions apply in more general ways such as disturbance of habitat.

In 1999 the World Health Organisation (WHO) produced a report admitting noise was problematic, complex in its makeup and difficult to assess in so far as the impact upon people is concerned.

This admission must also apply to all other creatures with hearing capability and it should be the responsibility of mankind to consider these effects with a marked degree of importance.

Frequent noise is potentially more of a nuisance than that emitted infrequently, yet frequency could be a matter of conjecture. Annually could be frequent in some circumstances and sufficient to drive species from their natural surroundings.

Indeed sound issued at irregular intervals might be more of an aggravation than that produced with regularity. Regular occurrence might lead to habituation. Bird Scaring devices for instance have adjustable timers and are allegedly more effective when firing intermittently.

The WHO issued guidelines on community noise but there are so many sources of noise that to list them individually would be difficult in the extreme. Perhaps therefore it is not surprising they did not mention low frequency noise from wind turbines for example. Mayhap because it seems the problem has only relatively recently become a public issue.

Some limited comment was made however regarding low frequency noise and they exemplified ventilation systems disturbing rest and sleep even at low sound levels. They also said 'it should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health' and 'the evidence on LFN is sufficiently strong to warrant immediate concern'.

Different people perceive sounds differently and much depends upon the individual levels of tolerance and what to them constitutes disturbance. Other creatures have lower acceptance levels, as their survival is more reliant upon instinct and interpretation of unusual sounds as a source of danger.

Human acceptance of sound is subject to the test of reasonability where each case of complaint is considered upon its own merit. Measurement criteria help assess levels at which hearing damage may ensue or a nuisance is established.

With other animals the threshold of reasonability can only commence with human standards applied judgementally to each creature and the environment in which it thrives, this in itself may be unreasonable.

Sound is multifaceted and can amongst other things; echo, resonate, reverberate; be stored for later reproduction and travel huge distance. Other aspects in play are loudness, tone, pitch, timbre, intensity, frequency, continuity, exposure, acceptability and what each of these means at any given moment.

Loudness for example is a listener's auditory impression of the strength of a sound and tone is sound of a distinctive frequency unlike sound across a range of frequencies, which is known as broadband noise.

Sound of a level, continuous or streaming nature over an unvaried duration of time is known as equivalent continuous sound.

Certain sounds can appear to be transient because they seem to raise, peak and fall if the source moves towards and then away from a fixed point. Examples are a jet flying over or a train passing by and are called sound exposure levels (SEL).

J. C. Doppler, an Austrian physicist first noticed in 1842 how sound appeared to shift in conjunction with the movement of the source. Henceforth it was known as the Doppler shift or Doppler effect.

The speed of sound depends upon the elasticity and density of the medium through which it travels. The measurement based upon the velocity in dry air at standard temperature and pressure (STP) is 331 metres per second or 750 miles per hour and is the generally recognised 'speed of sound'. Increasing air temperature by 10°C increases the air speed by 6mps thus the sound barrier is variable.

The sound barrier is the point at which something travels faster than the speed of sound. An aircraft is a prime example and as it approaches the speed of sound it experiences a sudden increase in drag and loss of lift. These are caused by the build up of sound waves, which then create shock waves at the front and back of the aircraft.

Ernst Mach another Austrian physicist first identified what would happen long before the barrier was broken by manmade flight. Mach numbers are named after him and are the ratio of the speed of a body or fluid to the local speed of sound, Mach 1 refers to local speed.

When the 'barrier' is broken by a flying object (usually an aircraft) it moves from subsonic to supersonic speed and creates a sonic boom. The shock waves created spread out and sweep across the ground behind the object often causing a double bang.

The speed of sound also increases with the density of the medium through which it travels**.** The medium is the means by which the sound is carried. Those most commonly identified are air or water but all kinds of mass can be conductive including the earth and human or animal tissue.

Examples of the speed of sound through conductive mass are water 1,500mps, iron 5,000mps with granite slightly higher. Sound will not travel through a vacuum because of the lack of mass.

Sound waves are known as compressional waves. Sound is caused by an oscillation in pressure creating stress particle displacement and particle velocity in a medium that results in an auditory sensation made by the particle fluctuation.

The compressed waves carry sound energy and the matter through which they travel vibrates in the same direction as the wave is travelling. The pressure oscillation or movement is stimulated into causing a vibratory effect that produces waves of energy. For purposes of simplicity it is the waves hitting our eardrum that we hear.

The strength of sound interpreted by the listener and called loudness is actually the average deviation above and below the static value. In turn it is dependent on sound energy and frequency, intensity, tone and then judged by the importance gauged by the listener's own attitude.

Loudness due to a sound wave is called sound pressure and is the physical resonance to sound pressure and intensity.

Resonance is the effect best described as being similar to the sound of blowing across the top of an empty bottle. It is caused by the increase in amplitude of vibration of an acoustic system when forced to vibrate by an external source and occurs when the frequency of the applied force is equal to the natural vibration frequency of the system. Large vibrations can be damaging.

Sound level meters measure sounds over a time period and then produce an average. Consequently they may not give an adequate impression of the disturbance of fluctuating sound. A gunshot for instance, would be a single sharp intervention of noise that would simply be included in the average.

The energy expended during sound wave vibration is identified as intensity and is actually the rate of flow of sound energy. This flow rate is measured in intensity units and these are called decibels (dB) a dimensionless unit which denotes the ratio between two quantities that are proportional to power, energy or intensity.

One of these quantities is a designated reference by which all other quantities of identical units are divided. The sound pressure level in decibels (dB) is equal to 10 times the logarithm (to the base 10) of the ratio between the pressure squared divided by the reference pressure squared.

If that were not confusing enough the study of sound is called acoustics where the reference pressure used are called micropascals.

Acoustics is the science of sound, including its production, transmission and effects. The acoustics of a room for example, are those qualities that together determine its character with respect to the perception of sound.

A single micropascal is one millionth of a pascal and a pascal is one newton per square metre. In water the common reference is 1 micropascal and in air 20 micropascals.

The latter is close to the absolute threshold for a normal human listener when emitted at a frequency of 1,000 Hz and is known as the sound-pressure level (SPL).

The micropascal references for air and water are 26 decibels (dB) apart, which whilst appearing small is significant.

The significance arises when comparing sound in air with sound in water because it is just one complication amongst many and considerable care is needed when making such evaluations.

Apart from the difference in reference pressure levels the impedances of air and water are not the same, which affects the power flow creating a different intensity even if the pressure levels are the same.

The need for comparing sound in air and in water arises frequently because of the differing and sometimes radical effects the same source of sound can have when applied to the two mediums simultaneously.

For example placing a swimming pool on a hotel roof. The sound of a diver plunging into the water has limited effect upon poolside sunbathers but to the occupants of a bedroom immediately beneath it is magnified and could be unbearable.

Similarly sound from a land-based source placed beside a pond would extend into the water and gain intensity. Imagine the effects upon the pond life if the sound was continuous. Creatures with legs and wings could escape but fish and other aquatic species do not have that luxury.

Fish can detect an angler's footfall long before his movement is noticed. A stone tossed into one end of a pond can disturb fish at the other. Low frequency sound from a bank-side source would travel in air across the surface slower than beneath the water and the pressure in the latter would be greater. Hence the sound would be 'felt' even if not actually 'heard' and be disturbing.

The area and depth of the pond, clarity of water, weed growth plus the nature of the bottom, composition of banks (earth, concrete, stone etc) and surrounding vegetation would all play a part in varying the effective level of disturbance. Added to these factors would be the Hz and dB levels of the sound as well as all the other features briefly touched upon in earlier paragraphs of these notes.

Mammals frequenting watery habitats such as Water Voles and Otters are prime examples of creatures with sensitive hearing. Yet voles often live alongside roads, bridges and railways intensively used by humans without apparent disturbance and otters are known to close their ears and nostrils when under the water.

Would either creature record hearing underwater noise? Surely they must because they have ears. The otter by closing ears and nose is not just keeping out the water but also attempting to prevent pressure damage to delicate membranes.

Could they 'hear' infrasound? Not if it were below the threshold of their 'normal' hearing but their nervous system would respond in a tactile manner and receive sensation. These are the type of questions that must be answered when embarking upon a study of the effects of low frequency noise upon animals in their landlocked kingdom.

Sound that passes through a medium like air or water produces a wavelike motion of compression and refraction. Wavelength is the distance between two identical positions in the cycle or wave and is similar to ripples or waves produced by dropping a stone in water.

Length of a sound wave varies with frequency. Low frequency equals longer wavelengths. The length is not the distance each wave travels but the measurement of the individual wave.

Sound waves have an enormous range of scale the extent of which is normally known as amplitude and are usually portrayed in frequencies. These are delineated in Hertz (Hz), which is the frequency of sound expressed by cycles per second (CPS). Our ears are sensitive to some of these frequencies.

Our sensitivity or 'hearing' normally registers frequencies between upper and lower levels of 20,000Hz and 20Hz. This is often referred to as the audio frequency range although sound as low or lower than 2Hz is capable of being heard by some humans.

Frequencies above 20,000Hz are named ultrasonic or ultrasound and below 16Hz are called infrasonic or infrasound, although sometimes the 20Hz level is used for convenience.

Infrasound, which is usually considered to be below the range of normal human hearing (20Hz), is nevertheless still heard but is not interpreted as being heard even if the vibrations are felt elsewhere on the body.

Strange as it may seem this has been shown to be true through experimentation at a concert hall in 2003[1]. Live music was played to an unsuspecting audience and afterwards they were asked for their reactions.

165 (22%) out of 750 in attendance confessed to unusual feelings of uneasiness and sorrow and experienced chills down their spines or nervousness including revulsion and fear. Some had increased heart rates or sudden memory of an emotional loss.

This scientific exercise was conducted by producing infrasound with a 7metre length of pipe and added to some of the four pieces of music played.

Neither the audience nor one of the scientists carrying out the experiment was aware which pieces were adulterated with 'silent sound'.

Questionnaires were issued and it was discovered that the odd sensations were only felt or experienced during the pieces accompanied by the infrasound.

The level of infrasound played has not been published but some organ pipes produce frequencies as low as 16.4Hz so the addition of an extra pipe suggests it was intended to produce an even lower Hz level.

Obviously some of the audience may normally have been able to hear sound at that level but the exercise still confirmed that the effect was unpleasant.

Sound heard by humans and considered as unwanted is more commonly called noise. The word noise is readily understood until trying to elaborate upon the meaning. The concert audience in the infrasound experiment did not hear a noise in the conventional sense but some were undoubtedly disturbed.

Infrasound is therefore sound emitted at low and very low levels of frequency and in general, is inaudible to the average human.

Other creatures however have different hearing levels and are able to discern frequency beyond and below the human range. Therefore it seems reasonable that if they heard the same infrasound as the human concert audience some would also have undergone an unpleasant experience.

Unlike the humans however they would probably have left early.

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[1] The Purcell Room, London

**MEASUREMENT OF INFRASOUND**

In many cases speed of sound through the earth and water is just as relevant to the production of infrasound as the speed of sound in the air.

Earthquakes produce seismic pressure waves that have been recorded as travelling through strong rock at about 6-7km per second (about 4 miles per second). Compared to air speed at 331 metres per second (1,086 feet per second) that is around 20 times as fast.

The speed at which a sound wave travels however is often less important than the frequency a sound is emitted and the intensity at which it is delivered.

For example the speed of sound waves emitted by a ticking watch do not normally matter as the frequency is of more interest for time keeping purposes. The intensity is also important, too great (loud) and it might be invasive. A human heart will try and tune to the regular pulsating of a clock on the bedside table.

Conversely the speed of sound emitted by a jet engine might be problematical because of both the speed of travel and the intensity of the pressure waves striking the ear.

To gauge the effect of infrasound upon land based and fresh-water creatures then concentration should be focused upon intensity and frequency as much as upon speed.

Low frequency sound and infrasound are normally separated for general classification purposes. This would seem to be for no other reason than one of convenience although two bands are often quoted.

Sounds with frequencies between 20Hz and 900Hz or by some definitions 16Hz and 400Hz are considered to be of low frequency. Infrasound is taken to be frequencies below 20Hz or 16Hz.

Loudness is the yardstick understood by most people although as has been seen even that is not simple to define as much depends upon the listeners perception in the first place.

What is loud to one person is acceptable to another. Yet at moderate levels, low frequency sounds are judged to be less loud than high frequency sounds when the sounds are of equal intensity.

Equal loudness contours are used to determine perceived loudness of a single frequency sound. Complex sounds consist of a variety of frequencies and the system developed to identify sound in such a manner is called A-weighting.

A-weighting is a general 'industry' standard and is used to obtain an index measure of community noise and expressed in A-weighted decibels (dBA).

Frequencies are weighted to simulate sounds of equal intensity at low sound levels and pure tones. Different level limits have to be used for different source types.

Problems arise if a single weighting is used for various sound pressure levels, as it cannot reflect the perception or other adverse effects of different noises.

Equal loudness contours based on broadband noise often are not applicable to community noises. This means there are limitations of A-weighted sound pressure level as a measure of loudness.

Another method of weighting has been designed for infrasound. It is called G-weighting and adopts assumed hearing contours with a slope of 12dB per octave from 20hz down to 2Hz. There are no established criteria for assessing low frequency noise levels in Great Britain.

When assessing the dB output of an air sound in water a figure of 26dB must be added. For example a super-tanker radiating noise in air at 164dB has an equivalent noise in water of 190dB. Which incidentally is louder than a jet engine. These are only approximations as amplitude often varies with frequency.

Sound moves about 4.5 times faster in seawater[2] (1,500mps) than in air (331mps) and faster still in warm water (although it will also increase with a rise in air temperature). Wavelength and frequency are related because the lower the frequency the longer the wavelength.

More specifically, the wavelength of a sound equals the speed divided by the frequency of the wave. Therefore a 20Hz sound wave in air is under 17metres long (331mps/20Hz = 16.6metres) whereas in water it is 75 metres in length (1500mps/20Hz = 75metres) and for land 325metres (6,500mps/20hz).

Descending below the surface of the sea slows the sound speed with decreasing temperature but pressure increases with depth and this causes the speed to rise again. In a deepwater channel for example, the sound waves bend or refract towards the area of minimum sound speed. Thus bend up and down repeatedly and can travel thousands of metres without very much loss of power because they are effectively trapped. This is known as a SOFAR (Sound Fixing And Ranging) channel.

Infrasound is not monopolised by manmade objects as it can occur naturally. Examples include the wind and waterfalls. The level, intensity, regularity and location of manmade low frequency noise are what appear to cause concern and of course being emitted where none existed previously.

During 1998 the US Navy commenced tests with equipment they called their Low Frequency Active Sonar (LFAS) system. The intention was to measure the effects of various levels of low frequency sound waves on singing humpback and sperm whales.

The test area off the island of Hawaii was one of the whales main breeding and calving grounds.

Concerned environmental groups indicated the decibel (dB) sound levels to be used in the experiment would exceed the sound of a jet plane engine at take off. No doubt they used this example as the general public could relate to the noise level and felt it unfair to subject the whales to this type of disturbance

The Navy rebutted the environmentalists' claims as inaccurate and on their behalf the National Marine Fisheries issued a statement. This advised the acoustic power of a jet at take off (180dB air) generates about 100 kilowatts. The acoustic power of the LFAS speaker (200dB water) would generate about 1 kilowatt or the equivalent of 1% of the sound level of a jet engine.

Notice the subtle differentiation between the level of decibels (dB) where one measurement relates to air and the other to water and also the reference to acoustic power. It seems the figures were not comparing like with like especially as sound does not react in water the same as in air.

Acoustic power is actually acoustic intensity and is not what is measured. It is acoustic pressure that matters and the change in pressure produced by the sound wave is what should be recorded. Sufficient alteration of acoustic pressure can cause pain in humans.

The law readily appreciates this and noise protectors are required under the auspices of such legislation as the various Health and Safety at Work Acts. Even relatively low levels of change can create confusion. A neighbour playing loud music whilst you are trying to sleep or study is a common example.

Suffice to say it transpired the information issued on behalf of the US Navy by accident or design had confused the issue by mixing their methods of measurement. The result was that it appeared the output from their LFAS system was much less powerful than the public perception of the sound of a jet plane at takeoff.

[2] Sharon Nieukirk, NOAA Ocean Explorer

Perhaps a more accurate illustration would have been to express the pressure levels generated by the sound underwater rather than compare decibels (dB) in totally different conducting mediums.

One person[3] did just this and used the figures supplied on behalf of the Navy and published his findings. Taking the energy output of 100 kilowatts (jet plane) and 1kilowatt (LFAS loudspeaker) he calculated even if the engine did generate 100 times the acoustic power of the loudspeaker the pressure wave from the latter was about 6 times stronger than the former.

He also utilised the decibel measurements quoted in the statement and equated them to air and water respectively. In this case the pressure level would have been something like 33 times greater in water, than in air, which is probably why it was not used on behalf of the Navy in rebutting the example.

The experiment went ahead and all the whales apparently left the area shortly after the tests commenced. This caused the Navy to cease testing prematurely and seems to have proved that whatever level of sound waves generated, the whales disliked them to such an extent that they left the breeding, feeding and calving grounds.

Other reasons may have caused the whales to leave but none that were recorded by the whale watchers. Furthermore it seems the following year there were far fewer whales that returned to the test area yet plenty elsewhere in the region.

Without knowing the Hz level at which the LFAS system was tested it cannot be categorically stated at what level the US Navy discovered (if indeed they did) that it caused disturbance to the whales.

It seems self evident however, that if a loud speaker releases acoustic intensity of around 200dB at source into a medium that has the capability of increasing pressure many times over then a serious amount of discomfort would be felt by the recipients.

After all the pain threshold generally quoted for humans is around 120dB -140dB in air. This means the normal bearable levels with some discomfort to prolonged exposure. Once these levels are exceeded they start to cause pain that gradually increases with the rise in decibels (dB) until it is unbearable and damaging.

On the other hand unless the pain threshold for a whale is known the effects of the broadcast cannot really be understood or appreciated. The difference between the ear of a whale and a man is considerable and the hearing range is not compatible either.

Land animals will desert habitats violated by noise and birds will often fail to return to a nest that has been disturbed even when eggs or young are present. Why should whales be any different? Yet they frequently return to areas where small boats and human ‘watchers’ appear and apparently without distress.

On the balance of probability alone it seems that at one end of the spectrum the whales simply did not like being disturbed and at the other might have experienced physical pain or even hearing damage. Either way it was caused by the deliberate attempt to expose them to the effects of infrasound.

Many other factors relating to the Naval experiment are also unexplained. For instance how far away was the equipment from the nearest whale? Did they follow the creatures or purely operate from a static location? These are simple but important questions because of the manner in which sound travels and loses pressure over distance.

The reference points for measurement in both air and water are based upon a distance of one metre from the source of the sound. (The Navy generated sound of 200dB was a powerful blast at this distance). Without hindrance the sound would radiate symmetrically. This is called spherical spreading and the acoustic

[3] Lee Tepley Ph.D. Physics

intensity decreases inversely with the distance squared and the pressure decreases inversely with the distance.

In other words without interference the sound wave dissipates regularly over distance and time until it probably disappears entirely. Hence the reason why a 'normal' sound a long way away from the source does not seem as loud as when up close. Yet as always with matters of sound there seem to be exceptions.

The whispering gallery in St. Paul's Cathedral springs to mind. The listener upon pressing an ear to the inner wall of the dome can hear an otherwise inaudible whisper from the opposite side of the chamber. In such a case the enclosed dome magnifies the sound. Could water act similarly?

Sea water in its natural environment is in a constant state of flux due to tides, wind, rain, large mobile objects like boats and because it is a fluid 'bounces' off rocks and shores etc. It also has a greater density than fresh water so any resistance to sound waves will differ to the water found in lakes, ponds, rivers and the like.

The movement and temperature of the sea will affect the manner in which it conducts sound waves. Cold water is more dense than warm. Moreover the depth will be a factor as well as the type of seabed because of the properties of resonance, reflection and absorption. Even the surface of the sea where it meets the air will distort the spherical spread.

In shallow water it seems the pressure waves are affected considerably and decrease approximately inversely to the square root of the distance from the source. This is called cylindrical spreading and would be extremely difficult to calculate accurately if the seabed was not of uniform flatness or consist of homogeneous material.

We know that water and air convey sound waves differently even before other complications are introduced. A simple published comparison[4] where all aspects of interference are disregarded confirms that a spherical sound source radiating a given pressure in ordinary freshwater when compared with the same source in air generates an intensity ratio about 5,000 times greater.

This is a very considerable pressure increase indeed and begins to explain why so many studies have been conducted into the effects of infrasound on marine creatures. Allowing for the greater density (about 1.5 times) of seawater it confirms why environmentalists are concerned.

Remember sound also travels faster in a mass of greater density than in air. Therefore the much greater pressure level is also delivered quicker making it more difficult to escape repetitive sounds

Furthermore it suggests a perturbing situation might exist for both freshwater dwellers and land-based creatures diving under freshwater in close proximity to sound sources emitting high intensity low frequency noise over long periods of time.

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[4] The National Academy Press

**INFRASOUND CONCERNS**

The use of sonar has not been the only cause for apprehension involving low frequency sound. Offshore drilling platforms used by the gas and oil industry and more recently the erection and prospective placement of wind turbines has featured strongly as worrying features in so far as the effects upon marine creatures are concerned.

Wind turbines seem to be causing more trepidation than drilling platforms and perhaps rightly so because of the sheer number already in place and the prospective proliferation as a reaction to the disquiet of climate change predictions.

Another reason for the focus upon turbines is by reason of where they have been placed and are likely to be erected in the future. The shallower regions of coastal waters, estuaries and perhaps the larger inland areas of water such as Lake Erie, USA are all considered ideal because they embrace some of the windier regions of the planet.

A recent press article[5] confirmed a tower rising 165ft above the surface of Lake Erie and three miles offshore has been installed to accommodate a weather station. The purpose being to gather data over a two year period as a pre-curser to installing wind turbines on the ecologically sensitive western end of the lake.

Unlike turbines off the seacoasts they would be in freshwater that freezes. A wildlife biologist has expressed concern because of the effects of noises and vibrations on creatures as small as mayflies that at one stage in their lives burrow beneath the lake sediment.

Oil drilling platforms have also posed problems in the sea. They cause low frequency noise that continues all the time they are in operation. Air drills are used that emit high intensity levels of infrasound and the pumps run around the clock. Wind turbines also emit more or less continuous output (when the wind blows).

Wind turbines are also situated on land where the effects upon the flora and fauna are easier to monitor but are nonetheless disturbing. Many instances of bird and bat deaths have been recorded. The wind industry has belatedly shown a degree of concern and there are recorded instances where chosen sites have been abandoned in deference to the potential impact upon wild life.

Accordingly it might be supposed, that if wind turbines were shown to have a substantial deleterious effect upon large sections of marine or land-based fauna, proposed sites where the exposure and danger to those creatures was most likely, would not be developed.

Unfortunately this is not always the case and besides, such a policy does nothing to reduce the risk where lesser immediate creature damage is concerned. Furthermore only limited steps have been taken to try and avoid mistakes from the past placement of turbines.

The wind industry has hitherto been slowly reactive rather than speedily proactive to the plight of birds and bats in relation to the problems caused by their turbines. The attitude always appeared to be one of first instance denial and it was not until overwhelming evidence was produced showing the mortality rates, that attempts were made to ameliorate the situation.

Some similarities appear to be developing with regard to low frequency noise emitted by wind turbines. Although it must be accepted that no known creature deaths have yet been recorded as the result of exposure to such noise the industry reaction seems to have been one of denial before investigation.

Infrasound effects upon humans from wind turbine generators were raised as a concern some years ago. Yet only recently have reports been released by the wind industry with results of desktop studies and none seem to have been conducted on wild animals at wind farms.

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[5] The Toledo Blade, Ohio – An article by Tom Henry, September 4th 2005

Neither do they appear to involve people monitoring. Whereas a medical practitioner[6] has studied the effects upon a group of her patients, all of whom live close to a wind farm and the initial results appear to endorse the concern that exposure to low frequency noise emitted by the turbines does have a detrimental affect upon health.

The lack of accumulated research on humans does nothing to dispel fears and leaves the wind industry open to accusations of concealment. Nor do they appear to have taken the next logical step to discover what the effects might be upon mammals other than humans.

Outside of the wind industry there is some evidence of research and an independent report[7] sponsored by a number of interested parties including the Society for Conservation of Marine Mammals was produced in 2003. It concluded that both harbour porpoises and harbour seals reacted to the water bourn simulated sound of a 2 MW wind turbine.

Operational underwater noise emitted at 8 metres a second by a 550 KW wind turbine was recorded from the sea in Fortune Channel, Vancouver Island, Canada and modified to simulate a 2 MW turbine. The replayed sound emitted maximum sound energy between 30Hz and 800Hz with peak source levels of 128dB at 80Hz and 160Hz.

Calm days were used and 375 porpoise groups and 157 seals were tracked. Porpoise echolocation clicks increased by a factor of two when the sound source was active. Seals surfaced at larger distances from the sound source. Both species therefore can detect low frequency sound generated by off shore turbines.

The report highlights the German Exclusive Economic Zone (beyond 12 miles off shore) of the Baltic and North Seas where power companies have applied for permits to build 30 large wind farms with a possible capacity of generating over 60GW of energy.

If all these wind farms were realised this would comprise 12,000 wind turbines, each of 5MW capacity (of which only a prototype exists) or 30,000 of the 2MW class. The area needed for such development would cover some 13,000km$^2$ and some sections are densely populated by harbour seals and harbour porpoises.

Other aspects of the report refer to the known problems relating to the release of high-intensity low frequency sounds in the sea. They propagate over long ranges and can mask echolocation sounds or calls from marine animals including predators or prey, disturb natural behaviour, cause hearing damage and physiological distress.

The report also states that during construction and operation of wind turbines, low frequency noise is emitted into the water. Referring to recent studies they indicate seals and harbour porpoises can hear sound in the frequency range typical for these operations.

In addition comment is made upon other experiments showing free ranging harbour porpoises leave an area when pingers have been operated to produce artificial sound. The inference being that any unusual sound causes the creatures to abandon an area.

Elsewhere it seems seals may also experience other more severe problems from wind turbines. A press report in 2005[8] said a wind farm at Scroby Sands off Great Yarmouth, Norfolk was blamed for the deaths of baby seals. It appears some of the pregnant seals were so disturbed by pile driving for foundations of wind turbines they aborted their pups. (Pile drivers emit infrasound as high as 230dB).

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[6] Dr Amanda Harry

[7] Behavioural reactions of free-ranging porpoises and seals to the noise of a simulated 2MW windpower generator - 2003

[8] The Mirror Newspaper – Reported 6th June 2005

Conversely a report prepared for the New Zealand Energy and Efficiency Authority[9] asserts that in so far as humans are concerned there is no reliable evidence that would indicate any effects when infrasound is present at a level below the human hearing threshold.

Whilst it is accepted this particular comment was made in the context of trying to identify any problems that infrasound from wind turbines may cause to humans, no reference was made to other animals and it is open to challenge, as there are references elsewhere to an opposing point of view.

Indeed there is a disease called Vibroacoustic Disease (VAD) resulting from exposure to high intensity, low frequency sound and infrasound. The condition is described as a chronic, progressive, cumulative systemic disease.

Admittedly the studies of the disease appear to suggest that it is environments with high intensity sounds over 110dB coupled with low frequency sounds below 100Hz that place people at most risk yet clearly do not preclude symptoms at dB levels below ordinary human hearing.

Neither do the studies exclude the effects upon animals with a similar hearing range to humans nor those that encompass ranges with lower cut off points.

The hearing abilities of creatures other than man are difficult to determine. Even with sea mammals where studies have been concentrated because of the fears surrounding the noise created by human activities, only relatively little research exists into the range of hearing.

There have been investigations involving harbour porpoises where it seemed wind turbine noise at source might be above their hearing range. But, the porpoises' hearing range depends on sound radiation and cylindrical spreading of low frequency sounds appears to change the picture.

The behavioural report following study of noise from a simulated 2MW turbine in respect of porpoises and seals previously mentioned does comment on this aspect. After making mathematical corrections to determine where and when the spherical sound wave from the turbine source became a cylindrical wave it discovered harbour porpoises could possibly hear the noise from a wind turbine.

Although not fully proven it opens the debate and would explain the creatures agitation when faced with the low frequency sounds that were hitherto believed to be inaudible to it.

Because of the lack of study in respect of land-based animals and infrasound it is necessary to look at the frequency hearing ranges of some of our more familiar creatures and domestic dogs are a good example.

Some animal species can be trained to respond to sound stimulus and can learn to make selections using rewards. Canines are particularly good subjects. Pavlov's dogs and the animal fired into space in a Sputnik confirm it works.

Setting up two dispensers containing food and drink and training animals to select one or the other by using pure tone sounds at varied frequencies (Hz) and different loudness intensities (dB) should enable mapping of the creatures hearing range.

Experiments of this nature have been done[10] and the results published. In general it was found that dogs had slightly greater sound sensitivity (detected lower intensity sounds) than humans whereas cats had greater sensitivity than dogs.

The greatest sensitivity in dogs i.e. the frequencies that can be detected at the lowest intensities was in the frequency range of 4Hz to 10Hz. One dog (a poodle) heard a tone at the low frequency of 40Hz but an

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[9] Bel Acoustic Consulting – Low Frequency Noise and Infrasound from Wind Turbine Generators: A Literature Review

[10] Lipman & Grassi, 1942. Heffner, 1983

intensity of 59dB was required for it to be detected. Most of the other dogs didn't respond until the stimulus frequency reached 62.5Hz.

On the other hand the poodle also heard a 4Hz tone when it was at an intensity of –4dB, which is a very soft tone. (The logarithm of a number smaller than one is a negative number, which explains why a negative tone was expressed). The same dog also heard an 8Hz tone when it was played at 3.5dB intensity.

There was no systemic relation seen among the dogs between high frequency hearing sensitivity and head size, body weight or tympanic membrane area. Presumably lower frequencies could have been established as 'heard' if louder stimulus was used and likewise for high frequencies.

Utilising information provided by the experiments and a variety of other sources a chart comparing the hearing ranges of a number of species is shown below: -

| Species | Lower Range (Hz) | Upper range (Hz) |
|---|---|---|
| Dog | 67 | 45,000 |
| Cat | 45 | 64,000 |
| Cow | 23 | 35,000 |
| Horse | 55 | 33,500 |
| Sheep | 100 | 30,000 |
| Rabbit | 360 | 42,000 |
| Rat | 200 | 76,000 |
| Mouse | 1,000 | 91,000 |
| Hedgehog | 250 | 45,000 |
| Ferret | 16 | 44,000 |
| Bat | 2,000 | 110,000 |
| Beluga Whale | 1,000 | 123,000 |
| Elephant | 16 | 12,000 |
| Porpoise | 75 | 150,000 |
| Goldfish | 20 | 3,000 |
| Bullfrog | 100 | 3,000 |
| Canary | 250 | 8,000 |
| Owl | 200 | 12,000 |
| Chicken | 125 | 2,000 |

The owl species is not known and all the figures are subject to variation from subject to subject but give a reasonable guide to the probable average levels concerned. Note that most of the dogs in the hearing experiment responded to sounds (62.5Hz), which are below their normal average hearing level (67Hz).

Apart from the ferret, elephant and goldfish it does seem none of the species can actually 'hear' the normally classified levels of infrasound frequency (20Hz and 16Hz), which places them broadly in the same situation as man.

The ranges do however pose certain questions. We have already established elsewhere that man is normally capable of detecting 20Hz and sometimes lower, which suggests the cow for example (lower range 23Hz) might respond in a similar manner to some of the humans attending the concert mentioned elsewhere in this text.

Indeed it is known that milk yields are affected by sound and instances of dairy farmers playing 'soothing' music to their herds are often reported in the press. Logically if bovines can appreciate the classics they would abhor the unpleasant effects of a concert laced with infrasound.

On the other hand the hedgehog with a suggested hearing range commencing at a level of 250Hz would seem to be oblivious to designated infrasound (14Hz or 20Hz). Yet anyone who has approached a hedgehog (they do not have particularly good eyesight) will have seen them 'freeze' at the tread of a footfall.

Their sense of smell might play a part but even once they have detected the onlooker and remain aware of their presence they still react to footsteps. Therefore it seems hedgehogs pick up on the vibrations of quite soft footsteps. The reason is probably due to the tactile reception of the lower frequency sounds.

Another chart[11]displays broadly similar ranges for the animals selected. The only real disparity being in respect of a rat where the lower level is shown as higher at 650Hz as opposed to 200Hz and the upper level is lower at 60,000Hz instead of 76,000Hz.

Differences are to be expected within the same species. Human hearing deteriorates with age as we all too soon discover. Animals suffer similarly as anyone who has 'owned' an elderly dog will testify. Hearing range is also affected by concentration. The child with its head in a good book is an example.

We know that humans 'heard' infrasound at a concert and experienced unpleasant effects. Harbour porpoises and harbour seals detected low frequency wind turbine noise and recent research confirms that elephants communicate by using rumbles at infrasound levels and 'feel' them through their feet as well as when placing their trunks on the ground.

Fish are easily disturbed by footsteps on the waterside bank and the lower reception level for goldfish (20Hz) shown in the chart appears to bear this out. With regard to the ferret perhaps the reason for such a low level (16Hz) is because it naturally hunts under ground where low frequency sounds are emitted by its prey scrabbling in burrows.

The fact that a Goldfish has a lower range identical to that of a human (20Hz) is an interesting aspect. Fish as we know spend their lives under water. When we operate in this environment without earplugs many sounds heard seem muffled and indistinct.

Divers upon hearing the steady beat of the water screw from an engine driven boat have difficulty in pinpointing the craft until it is nearly overhead. It is heard long before it is within vision but appears to be coming from different directions at the same time.

Likewise an observer on land may have problems locating the direction of approach of a Helicopter obscured by low hills or trees until it is nearby. Hence one reason why the military practise tree-hopping attack exercises.

In both cases the low frequency rhythmic sound is spread out by the effect of the surroundings that act as a conductive medium. The source of the diffused sound becomes difficult to identify. This should be neatly shown by the manner in which a shoal of fish reacts when disturbed by low frequency noise.

They should scatter at first because the cause of 'danger' is real but not immediately visible and each fish should act according to its own interpretation of the safest haven. They could then regroup away from the noise source.

We know they can actually be herded by release of regular bursts of sound. Dolphins practise a similar routine when hunting and 'round up' shoals. Why then does a low frequency noise such as dropping a stone into the pond not produce the scattering effect within the shoal?

Any angler will tell you they do not disperse but move rapidly away in unison. This should not happen. Especially if the sound source and cause of fright cannot be instantly located.

The answer is that fish have a lateral line system. This provides information about water flow to each fish. As one fish moves in a certain direction, it creates a flow of water that triggers the fish next to it to follow

[11] H.R Schiffman – Sensation and Perception. An Integrated Approach. 2001

suit. A chain reaction develops resulting in the entire school of fish moving as one large mass in the same direction.

The nervous system of a fish however should be singularly less complex than for a human. They are cold blooded and do not, as far as is known, experience pain in a similar manner to warm blooded creatures. Nevertheless they display elements of fear and are easily disturbed into flight.

Surprisingly fish have two sensory systems that enable them to be aware of their surroundings by sensing vibrational information, both make up what is called the acoustico-lateralis system. These two systems detect sound and vibration respectively and are called the inner ear and the lateral line.

Fish use the lateral line system to detect acoustic signals over a distance of one or two body lengths and at low frequencies (lower than 160Hz to 200Hz). Organs called neuromasts detect the relative motion between the animal and the particles in the surrounding water. These have hair cells that can move, sending nervous signals to the brain.

Fish bodies are closer in density to water than air. Sound waves cause the entire fish to move with the water and sound passes right through their bodies. Bones in their inner ear called otoliths are made of calcium carbonate. These chalk like bones are much denser than water and the rest of the fish, so they move slower than the main body of the creature.

The difference between motion of the fish and the otoliths stimulate cilia on the sensory hair cells. This movement is interpreted as sound. The range of frequencies detected by fish (20Hz – 200Hz in Goldfish) is within the low frequency levels.

Although sensitivity to sound differs among fish species the thing that affects this is the proximity of the inner ear to the swim bladder. This bladder is gas filled and therefore has a much different density to either the rest of the fish or the water in which it lives.

Consequently the swim bladder can be easily compressed by sound pressure waves. The bladder pulsates in reaction to sound waves causing the tissues of the fish associated with it to move. Some species such as carp and catfish have the swim bladder connected to the inner ear via a bony system, which increases their hearing sensitivity.

On balance it seems reasonable to accept a fish would detect infrasound at Hz levels below its normal hearing range, but what degree of distress would be derived can as yet only be surmised. Fish deaths have been recorded from the use of underwater explosive due to pressure waves rather than the direct impact of the explosion.

Only minimal damage need be caused to the lateral line, the swim bladder or inner ear for death to result. The magnitude of Hz levels would seem to be the overriding factor when trying to establish what harm would occur from positioning an infrasound source near to fish habitats.

If infrasound instead of low frequency sound were emitted i.e. at levels below 20Hz then by virtue of the hearing limitations of fish it would be felt and not heard.

Consequently as water is a much better conductive medium than air it would take very little pressure from emitted infrasound to be registered by the fish. The unseen pressure waves would spread just the same as low frequency noise and travel long distances.

It has already been mentioned that sound in water operates at increased pressure over sound in air and we know infrasound in air at a concert caused human suffering. Therefore it is reasonable to suppose a greater degree of distress would be caused in water.

In fact following what is believed to be the first study of its kind and reported in 2003[12] Prof. Arthur N Popper and his colleagues found that loud man-made noise significantly damaged fish in the wild. Their study found the injury to fish ears, and thus hearing, was significantly greater than they had anticipated.

The research took place in Jervoise Bay, Western Australia on pink snapper fish. The noise-maker was a seismic air-gun, a tool routinely used to search for underwater oil deposits. The air-gun sound is sent repeatedly through the water, travels to sub-sea rock strata and back up again.

Fish were placed in a cage at varying distances from the air-gun and exposed to differing levels and repetitions of sound from the gun. When examined, holes were found in the hearing part of the fish ears, in the region where it was expected to find sensory hair cells. The hair cells had either been ripped away or there was evidence that the cells were dying.

The study indicated that unlike humans the hair cells of fish are normally able to regenerate but found this had not occurred after nearly a month. With ears similar to other vertebrates, including mammals, most fish use sounds to detect predators, find prey and communicate to find mates. Loss of hearing can therefore leave fish very vulnerable.

Although fish swimming freely are able to swim away from the sound, the report advised that behavioural studies had shown some fish exposed to air-gun signals did display disoriented swimming behaviour. Prof. Popper said the results of the study suggest caution in using devices that make intense sounds in environments inhabited by fish and mammals.

Another study, this time under laboratory conditions was published online in December 2003[13] and relates specifically to goldfish. The findings following exposure of the fish to high levels of white noise (above infrasound frequency) confirmed they sustained initial physiological stress responses as well as short and long-term hearing loss.

Some interesting comments were also made by the study confirming that a 100Hz tone may be detected by the lateral line as well as by ear hence researchers have not generally performed auditory brainstem response tests below 200Hz, probably to avoid stimulating the lateral line response.

Furthermore due to the 40dB loss of sound energy at the air-water interface determined by Parvulescu in 1964, very little sound was heard outside the noise tanks used to conduct the underwater noise experiments. Consequently no noise from a tank containing a loudspeaker and sound source escaped to the control tank where fish not subject to sound exposure were housed. The maximum dB level used was 170dB underwater.

The experiment also stated that sound is an important means of communication in aquatic environments because it can be propagated rapidly (five times faster than in air) over great distances and it is not attenuated as quickly as other signals such as light or chemicals. Which they conclude is a reason why fishes and marine mammals make considerable use of sound for communication etc.

Whales issue sonar type noises as apparent methods of communication. These sounds fall within the ultrasonic classification (the opposite end of the range to infrasonic) but they also receive infrasound as demonstrated by the disturbance when bombarded with the US Navy signals. Whales are said to avoid areas commencing at 120dB.

Humpback whales and Bottle Nose dolphins are quite vocal and the sounds recorded from their emissions have ranged between 10Hz and 200,000Hz so it is reasonable to assume they hear across a similar range. The intensity of the sounds made are variable and not easy to measure, mainly because with the larger species it is very difficult to get close enough to record the sound without causing disturbance.

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[12] Journal of the Acoustical Society of America – January 2003 issue
[13] Noise-induced stress response and hearing loss in goldfish – The Journal of Experimental Biology

There is a reported instance of a vet being pushed back several feet into the water by distress calls made by a beached whale. This seems to demonstrate they do emit high intensity low frequency sound, either in pain or under some other form of duress. It also shows the force generated by infrasound in water.

An article about sea life and infrasound[14] indicates it is known that certain whales are able to stun their prey with powerful blasts of inaudible sounds. They apparently focus these ‘gunshots’ on large squid and other fish to paralyse and catch them. In some instances they are reported to have burst their prey by tonal projection alone.

Unfortunately if correct this then begs the question, ‘why do they not also damage themselves?’ Perhaps because they have the capability of forcing the infrasound waves along a directional course that when emitted at high intensity become virtually unstoppable until striking their target.

This is not as fanciful as it seems because it is well documented that military experiments have been carried out to try and harness infrasonic sound as a weapon. Bullets of acoustic power may seem fanciful but in 1972 an infrasound generator was in operation in France that when activated made people within range sick for hours.[15]

A Russian device that can propel a 10Hz sonic bullet the size of a baseball hundreds of yards is thought to exist. Blunt object trauma is caused to a target when a bolt of high power, very low frequency sound waves are emitted from one or two metre sized antenna dishes.

The US Navy experiment mentioned previously using LFAS upon whales was a military device for anti-submarine warfare. It emits up to 240dB and the US Navy sets 140dB as the maximum level of safe exposure to humans.

In the Second World War, German engineers constructed a prototype sonic ‘cannon’, which fired a shock (sound) wave strong enough to bring down an aeroplane.[16] Infrasound was used by the Nazis to stir up anger amongst crowds assembled to listen to Hitler.

Hitler also ordered experiments to be conducted on prisoners who were tortured with high intensity low frequency sound emitted by a weapon powered by compressed air.

According to an item of reported BBC news some US interrogators used amplified music including low frequency sound in 2003 to try and ‘break’ the will of Iraqi prisoners. This incurred the wrath of Amnesty International.

Previously psycho-acoustic tactics were used successfully by US troops in ‘Operation Just Cause’ in 1989 to remove Manuel Noriega from behind his barricade in Panama and the FBI are alleged to have played all manner of sounds at the Waco siege in Texas to try and disorient their opponents.

Prior to this, in 1973 the British Army tested an ‘Acoustic Squawk Box’ in Northern Ireland. Two ultrasonic frequencies (the opposite end of the spectrum to infrasound) were emitted and when mixed in the human ear caused giddiness, nausea and fainting. A small beam could be directed at individuals and used as a riot control device.

Earlier (pre-1973) a crowd control device, the Acoustic & Optical, Photic Driver was developed, again using ultrasound, which when combined with flashing infrared lights to penetrate the human eyelid was believed to have been used by the South African Police as an interrogation device.

Although these two examples relate to very high frequency sound it seems the results are similarly harmful where low or high frequency emissions are used with intensity.

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[14] Infrasound by John Cody
[15] Glossary of Non-lethal Weapons Terms, edited by Robert Bunker
[16] Feel the Noise by Jack Boulware

Another illustration was reported in The Toronto Star, Canada on 6th June 2005 when witnesses described a minute-long blast of sound emanating from a white Israeli military vehicle. Within seconds, protesters began falling to their knees, unable to maintain their balance. An Israeli military source, said “the intention is to disperse crowds with sound pulses that create nausea and dizziness.”

Professor Hillel Pratt, a neurobiologist specialising in human auditory response at Israel’s ‘Technion Institute’, says “It doesn’t necessarily have to be a loud sound. The combination of low frequencies at high intensities, for example, can create discrepancies in the input to the brain.”

Later he explained, “that by stimulating the inner ear, which houses the auditory and vestibular (equilibrium) sensory organs with high intensity acoustic signals that are below the audible frequencies (<20Hz), the vestibular organ can be stimulated and create a discrepancy between inputs from the visual system and somatosensory system (that report stability of the body relative to the surroundings) and the vestibular organ that will erroneously report acceleration (because of the low-frequency inaudible sound). This will create a sensation similar to sea or motion sickness. Such cases have been reported and a famous example is workers in a basement with a new air-conditioning system that all got sick because of low frequency noise from the new system.”

There are a great number of articles that include reference to the effects of infrasound upon humans. The frequency ranges are recorded in many of these and the overall result always appears to depend upon the exposure time when coupled with the dB and Hz levels.

A few seconds is all it takes at very low Hz and high dB levels before severe problems arise. Even at a level of dB normally found comfortable for listening to music for example, if the Hz level is low then significant adverse reaction has been reported.

Very low frequency sound can travel long distances, penetrate buildings and vehicles and does not significantly diminish its properties when it changes mediums such as from air to tissue. This is because unlike ultrasound it travels ‘in band’ more effectively due to the propensity of low frequency sound waves to travel in a straight line.

Intermittent bursts of infrasound would presumably not be as damaging as continuous exposure and if the levels of both cycles per second (Hz) and strength (dB) were not high then it is possible that little or no adverse effect would be delivered. Regular or irregular pulsating strong infrasound would however, at least be debilitating.

It is the level of tolerance that must be anticipated if any meaningful comment can be made upon the likely detrimental result of infrasound exposure upon wildlife whether inhabiting urban, suburban or countryside areas.

A research paper, ‘Human Body Vibration exposure and its Measurement’ by G Rasmussen looked at body vibration exposure at frequencies of 1Hz –20Hz. Part of a table shows:

| **Symptoms** | **Frequency** |
|---|---|
| General feeling of discomfort | 4Hz – 9Hz |
| Head symptoms | 13Hz – 20Hz |
| Influence on speech | 13Hz – 20Hz |
| Lump in throat | 12Hz – 16Hz |
| Chest pains | 5Hz – 7Hz |
| Abdominal pains | 4 Hz – 10Hz |
| Urge to urinate | 10Hz – 18Hz |
| Influence on breathing movements | 4hz – 8Hz |

A graphical illustration of a 'mechanical man' in the paper indicates the head will vibrate at about 25Hz and the chest wall at 60Hz. The paper then refers:

"Also, in the region 60Hz to 90Hz disturbances are felt which suggest eyeball resonances and a resonance effect in the lower jaw-skull system has been found between 100Hz and 200Hz."

There is reason to suppose that similar effects would also occur with wild animals if exposed to the sounds for long enough periods. The presumption must be that as soon as they felt uncomfortable they would move away from the zone of discomfort. A term more properly described, as disturbance and displacement, which in the case of 'protected' species would be contrary to appropriate legislation.[17]

As already mentioned test results upon humans have been released and the following examples are just some more extracts from differing sources that seem relevant.

According to one publication[18] when discussing the effects of infrasound at the rate of 1 – 10 Cycles per second (Hz) - "lethal infrasonic pitch lies in the 7Hz range. Small amplitude increases impact upon human behaviour in this cycle range. Intellectual activity is first inhibited, blocked and then destroyed. As the amplitude increases some disconcerting responses have been noted and begin a complete neurological interference. The action of the medulla is physiologically blocked and its automatic functions cease."

In another[19] also commenting upon the 7Hz level – "the most profound effects at this infrasonic level occur here. Seven Hz corresponds with the alpha-rhythm frequencies of the brain. It is commonly alleged that this is the resonant frequency of the body's organs and hence organ rupture and death can occur at high intensity exposures."

Scientific Applications and Research Associates (SARA) in America, alleged infrasound at 110-130dB would cause intestinal pain and severe nausea. Extreme levels of annoyance or distraction would result from minutes of exposure to levels 90 – 120dB at low frequencies (5 – 200Hz), strong physical trauma and damage to tissues at 140dB – 150dB and instantaneous blast wave type trauma at above 170dB.

Infrasound Toxicological Summary (USA), November 2001 stated – "When male volunteers were exposed to simulated industrial infrasound of 5Hz and 10Hz and levels of 100 and 135dB for 15 minutes, feelings of fatigue, apathy and depression, pressure in the ears, loss of concentration, drowsiness and vibration of internal organs were reported. In addition effects were found in the central nervous system, the cardiovascular system and the respiratory system."

This summary also confirmed amongst other things that respiration rate was significantly reduced after the first minute of exposure. The heart rate increased during the initial minutes and heart muscle contraction reduced. All of which must have been most unpleasant.

A Polish study, Medycyna Pracy Vol. 55 (1) 2004, p.63 –74 comments as follows:

"There is a growing body of data showing that low frequency noise (LFN) defined as broadband noise with dominant content for low frequencies (10Hz – 250Hz) differs in its nature from other noises at comparable levels. The aim of this study was to assess the influence of LFN on human mental performance. Subjects were 193 male paid volunteers…….LFN at 50dB(A) could be perceived as annoying and adversely affecting mental performance." (i.e. concentration and visual perception).

Some years ago Walt Disney and his artists apparently felt the effects of infrasound released accidentally at 12Hz on one occasion. A cartoon sound effect was slowed from 60Hz via a tape-editing machine and amplified through the theatre sound system. The resulting tone, though brief in duration, made the entire crowd nauseas and the effects lasted several days.

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[17] The Habitats Directive (Bern Convention), The Wildlife and Countryside Act 1981
[18] The Sonic Weapon of Vladimir Gavreau by Gerry Vassilatos
[19] Acoustic Trauma: Bioeffects of Sound by Alex Davies

Moviemakers use infrasound to produce unease and disorientation in the audience. A French film called Irrevérsible used this to considerable effect to highlight the disturbing visual content and increase the tension.

In order to bring the levels of infrasound into perspective it should be remembered that the human brain functions as a transmitter and receiver. In his paper, 'EEG Measurement', G Blundell states:

| | | |
|---|---|---|
| "The brain operates; | Normal activity | 13Hz – 30Hz |
| | Relaxed | 8Hz – 13Hz |
| | Drowsiness | 4Hz – 7Hz |
| | Deep Sleep | 0.5Hz – 4Hz |

Interrupting, conflicting or overriding signals of unwanted sound (perceived as noise) at any frequency will have an effect on the brain and associated senses but predominantly auditory functions and those directly connected via the ear. The lower frequency sounds (<20Hz) stand a greater chance of interference with operation of the brain.

The evidence appears to show that harm created by LFN to humans, ranges from simple sleep disturbance (aggravating in small doses, dangerous through fatigue if prolonged) through temporary disablement (sometimes deliberately imposed) to the extreme cases of permanent injury and possible death.

In the circumstances the medical implications are worrisome. A number of studies have been conducted into the health risks caused by body vibration from infrasound, increased cortisol from infrasound, endocrine effects and cardiovascular risks arising from noise exposure. (See Appendix A).

The problem with infrasound is that a doubling of loudness occurs when the level of the sound is increased in air by 5dB and at the same time it becomes about three times as intense. Therefore only a small increase in source sound can be significant.

Erection of barriers can reduce some types of noise and are most effective when close to the source, but are not very effective in tackling low frequency sound and infrasound. These sounds are very hard to muffle as they spread easily in all directions and may be heard for miles and are mostly perceived not as sound but as pressure.

Sounds at low frequencies are not well attenuated by atmospheric absorption[20] and precipitation can affect ground attenuation. Snow can have a muffling effect on the ground but the associated low air temperature can create a noise increase and spread the sound over longer distance.

Reflection of sound by substances of differing acoustical hardness will have an effect. Concrete or water will reflect more than grass, trees or other vegetation. Yet when prominent low frequency components are present the annoyance factor generally increases due to either vibration, greater pressure intensity or a combination of both.

The concerns of the effects of infrasound are clearly real whether they are upon humans, marine life and freshwater creatures or land based animals and in extreme cases the results of high levels of exposure could be lethal. Even relatively low levels can be debilitating and create disturbance.

On the other hand are the known emission sources on land capable of producing damaging levels of sustained sound in habitats frequented by land-based and freshwater creatures or do they just create a nuisance that might cause temporary fright?

Dr P L Pelmar contributed a section to a report commissioned by DEFRA in May 2003 (A review of Published Research on Low Frequency Noise and its Effects by Dr Geoff Leventhall and others) where he reviewed the effects of LFN on health. Within this review he stated, "The results of some animal studies

[20] Source: Bruer & Kiaer (Denmark), Environmental Noise Booklet

reporting adverse effects from infrasound exposure may be relevant for indicating possible human health effects."

The following is a summary of the studies:

a) Vascular – Myocardium

Alekseev (Alekseev et al.,1985) exposed rats and guinea pigs to infrasound (4Hz – 16Hz) at 90dB to 145dB for 3 h/day for 45 days and a single exposure (4Hz – 10Hz) at 120dB to 125dB. The latter led to short-term arterial constriction and capillary dilation in the myocardium. Prolonged exposure led to nuclear deformation, mitochondrial damage and other pathologies. Effects were most marked after 10Hz to 15Hz exposures at 135dB to 145dB. Regenerative changes were observed within 40 days after exposure.

Gordeladze (Gordeladze et al., 1986) exposed rats and guinea pigs to 8Hz at 120dB for 3h/day for between 1 and 40 days. Pathalogical changes in myocardial cells, disturbances of microcirculation and mitochondrial destruction in endothelial cells of the capillaries increased in severity with increasing length of exposure. However, changes were reversible after exposure ceased.

Rats and guinea pigs exposed to infrasound (8hz or 16Hz) at 120dB for 3 h/day for 1 to 40 days showed morphological and physiological changes in the myocardium. (Nekhoroshev and Glinchikov, 1991).

b) Conjuntiva

Male rats exposed to infrasound (8Hz) at 100dB and 140dB for 3 h/day ranging from 3 to 25 days showed constriction of all parts of the conjunctival vasculartrure within 5 days (Svidovyi and Kuklina, 1985). Swelling of the cytoplasm and the nuclei of the endotheliocytes accompanied the decrease in the lumen of the capillaries. The capillaries, pre-capillaries and arterioles became crimped. Morphological changes were reported in the vessels after exposure for 10, 15 and 25 days. After 25 days increased permeability of the blood vessels led to swelling of tissues and surrounding capillaries and to peri-vascular leukocyte infiltration. Significant aggregates of formed elements of the blood were observed in the large vessels.

c) Liver

Infrasound exposure damaged the nuclei apparatus, intracellular membrane and mitochondria of rat hepatocytes in vivo (Alekseev et al., 1987). Infrasound (2,4,8 or 16Hz) at 90dB to 140dB for 3 h/day for 40 days induced histopathological and morphological changes in hepatocytes from rats on days 5 – 40. Infrasound (8Hz) at 120dB to 140dB induced pathological changes to hepatocytes from the glandular parenchyma and sinusoids.

Morphological and histochemical changes were studied in the hepatocytes of rats and guinea pigs exposed to infrasound (2,4,8 or 16Hz) at 90, 100, 110, 120, 130 or 140dB for 3 h/day for 5 to 40 days (Nekhoroshev and Glinnchikov, 1992a). Hepatocytes showed increased functional activity but exposures for 25 and 40 days induced irreversible changes. Changes were more pronounced at 8 and 16Hz than at 2 and 4Hz. Exposures impaired cell organoids and nuclear chromatin. Single exposures did not induce any changes in the hepatocytes and small blood vessels.

d) Metabolism

(Shvaiko et al., 1984) found rats exposed to 8Hz at 90, 115 or 135dB exhibited statistically significant changes in copper, molybdenum, iron and/or manganese concentrations in liver, spleen, brain, skeletal muscle and/or femur compared to concentrations in the tissues of controls. Practically all tissues showed significant changes in all the elements for exposures at 135dB. Changes included elevations and depressions in concentrations. The trends were consistent with increasing sound pressure except for some copper values.

e) Auditory

(Nekhoroshev, 1985) exposed rats to noise of frequencies 4, 31.5 or 53Hz at 110dB for 0.5h, 3h or 3h/day for 40 days. Infrasound exposure caused graver changes than exposure to sound at 31.5 or

53Hz. Changes observed after exposure to this acoustic factor included reduced activity of alkaline phosphotase in the stria vascularis vessels and their impaired permeability. Impaired labyrinthine hemodynamics led to neurosensory hearing impairment.

(Bohne and Harding, 2000) sought to determine if noise damage in the organ of Corti was different in the low-and-high frequency regions of the cochlea. Chinchillas were exposed for 2 to 432 days to a 0.5Hz (low frequency) or 4kHz (high frequency) octave band noise at 47dB to 95dB sound pressure level. Auditory thresholds were determined before during and after noise exposure.

The cochlea were examined microscopically, missing cells were counted and the sequence of degeneration was determined as a function of recovery time (0 – 30 days). With high frequency noise, primary damage began as small focal losses of outer hair cells in the 4 – 8kHz region. With continued exposure damage progressed to involve loss of an entire segment of the organ of Corti along with adjacent myelinated nerve fibres.

With low frequency noise, primary damage appeared as outer high cell loss scattered over a broad area in the apex. With continued exposure, additional apical hair cells degenerated, while supporting cells, inner hair cells and nerve fibres remained intact. Continued exposure to low frequency noise also resulted in focal lesions in the basal cochlea that were indistinguishable from those resulting in high frequency noise.

In guinea pigs low frequency pressure changes have been shown to cause head and eye movements (nystagmus) of the animals for square wave pulses with pressure above 150dB (Parker et al., 1968).

f) Brain
(Nishimura et al., 1987) suggested from experiments on animals that infrasound influences in rat's pituitary adreno-cortical system as a stressor and that the effects begin at sound pressure levels between 100 and 120dB at 16Hz. The concentration of hormones shows a slight increase with exposure to infrasound. In the task performance a reduction was seen in the rate of working. It seems probable that concentration was impaired by infrasound exposure.

(Nekhoroshev and Glinchikov, 1992b) exposed rats and guinea pigs to 8Hz at 120 and 140Db for 3 hours for 3h/day for 5, 10,15, 25 or 40 days and they showed changes in heart, neurons and the auditory cortex increasing in severity with increasing length of exposure. The presence of hemorrhagic changes are attributed mostly to the mechanical action rather than to the acoustic action of infrasound. They suggested that changes in the brain may be more important than the ears.

g) Lung
Histopathological and histomorphological changes were determined in the lungs of male albino mice exposed to infrasound (2, 4,8 or 16Hz) at 90 to 120dB for 3h/day for up to 40 days (Svidovyi and Glichikov, 1987). After prolonged exposure to 8Hz at 120Db sectional lungs revealed filling of acini with erythocytes and thickening of inter-alveolar septa; after prolonged exposure to 8 and 16Hz at 140dB sectioned lungs revealed ruptured blood vessel walls, partially destroyed acini and induced hypertrophu of type-ll cells.

These results are quite chilling, as it is clear that deformities, damage and impairment occur with regularity. Admittedly the animals were contained and subjected to exposure times of several hours per day at moderate to high intensity, low frequency and infrasound levels. It would be most unusual for any comparative wild creature (say brown rats, field mice, bank voles or squirrels) to undergo similar exposure times or levels, but fish and aquatic creatures contained in ponds and lakes would certainly be unable to escape whatever the level of sound intensity.

On the other hand the experiments (with the exception of the Chinchillas) ceased after only around 40 days. Noise from factories, roads and other anthropological sources such as wind farms would be virtually continuous for year upon year, although not necessarily at such intensity.

This leads to a question. What would be the result of exposure to low Hz levels at less intensity for 25 years (the projected useful life of a land based wind turbine for example)? Bearing in mind the lowest sound pressure level used in the tests was 47dB (upon Chinchillas) and it seems to have contributed towards ear hair cell degeneration it appears likely there would still be adverse effects. Some species of fish, such as carp live in excess of 20 years.

Would animals become accustomed to the problem if the disturbance was only of a relatively minor level or could even small amounts of disruption lead to abandonment of habitation?

How would fish and invertebrates fair being unable to escape from enclosed pond environments? What degree of creature disturbance or destruction is acceptable or what is unacceptable?

The following two paragraphs are contained within a study published in 1988[21] and whilst the research was predominantly concerned with aircraft noise, particularly sonic booms it called upon a number of previous experiments and findings to illustrate the broad problem of noise upon animal welfare.

Popper and Clarke (1976) studied the hearing of salmon (Salmo salar) in the sea and in the laboratory. The fish responded only to low-frequency tones (below 380 Hz); particle motion, rather than sound pressure, proved to be the relevant stimulus. The sensitivity of the fish to sound was not affected by the level of sea noise under natural conditions, but hearing is likely to be masked by ambient noise in a turbulent river. Sound measurements made in the River Dee, near Aberdeen, Scotland, led to the conclusion that salmon are unlikely to detect sounds originating in the air unless the source is nearly directly overhead, but they are sensitive to substrate-borne sounds. Compared with carp and cod, the hearing of the salmon is poor and more like that of the European perch (Perca fluviatilis) and the plaice (Pleuronectes platessa).

To clarify the effects of construction sounds on fish populations, the change in acoustic environment of Lake Biwa (Japan) caused by dredging was observed (Konagaya 1980b). The response of fish to dredging sounds and the swimming direction of fish near the worksite were studied using acoustic biotelemetry. The spectrum level of the background noise of Lake Biwa was within the limits of prevailing noise of the sea. The sound pressure level of the underwater sound of a dredging boat at a distance of 150metres was about 38 dB, and that of a submerged pipe at a distance of 2metres was 75 dB. The fish showed negative responses and avoided the acoustic field of the worksite**.**

Both examples clearly show that noise and the related water disturbance do have an affect upon fish. Logic suggests this would be the case but what would prolonged exposure do? Perhaps a pointer is another study also reported in the above 1988 paper produced by Karen M Manci and her associates in respect of investigation into the effects of low frequency sound upon Brown Shrimp.

Growth and reproduction of brown shrimp (Crangon crangon) reared in a soundproof box that reproduced acoustical conditions similar to those prevailing in the shrimps' natural environment were compared to those of shrimp from the same source but reared in acoustical conditions prevailing in a thermo-regulated aquarium where noise levels reached 30 dB in the 25 to 400 Hz range (Lagardere 1982). This permanently high sound level resulted in a significant reduction in growth and reproductive rates. To a lesser degree, noise also appeared to increase aggression (cannibalism) and mortality, and to decrease food uptake. Symptoms were extremely similar to those induced by adaptation to stress.

Freshwater shrimp are a food source to many species of pond and lake dwellers. Reduction in numbers could impact severely upon creatures placed further up the dependency chain from fish to reptiles, birds and mammals. Interference at low levels of mortality may not be particularly significant over a wide area

[21] Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife: Karen M Manci et al.

of population, but the concentrated destruction of small invertebrates over a broad ranging spectrum of habitats could lead to an ecological break down of the food chain with far reaching consequences.

Amphibians such as frogs and toads also rely heavily upon sound for communication and this plays a substantial role in their reproductive behaviour.  Most amphibians have complex ears that are dependent upon sound frequency and directionality.

Whilst to the casual listener the croak of one frog may seem very like that of another studies have shown that closely related species, or even local populations of those with disjunctive distribution are known to differ.  The vocal harmonics, frequencies and intensities are quite marked.  Call duration, repetition and trill or pulsation rates differ widely.

Griffin and Hopkins (1974) measured sound levels of bullfrog (rana catesbieana) choruses at about 20dB SPL in the 1.5 to 2.5kHz frequency band up to 965metres above small ponds.  Uninterrupted sound travels upward much farther and more predictably than along a surface so it seems the sound serving as a stimulus to the frogs probably occurs within relatively narrow variation limits.

Acoustic avoidance behaviour was demonstrated in a natural population of the neotropical treefrog (Eleutherodactylus coqui) by a study (Zelick and Narins 1980).  The threshold for evasive action at different frequencies varied from 230Hz to 3,420Hz at between 60 – 70dB SPL.

Single tone stimuli (1-2 second duration), spaced at the frogs spontaneous call interval (2 –3 seconds), were presented to the frogs.  The creatures redistributed their calls in time such that the calls fell almost exclusively within the brief time window between tone bursts, thereby avoiding an overlap with the tone.

The average background noise level at the frog’s calling site was 30dB SPL at 500Hz, 59dB SPL at 1,000Hz and 66dB SPL at 2,000Hz.  Thus avoidance behaviour was observed at stimulus levels barely exceeding the noise floor of the frog’s environment.  Disturbance or confusion by introduction of lower frequency noise could also have an adverse affect upon receptive sensitivity.

What would happen if obfuscation occurred due to the introduction of continuous or virtually continuous infrasound or low frequency noise during the brief breeding cycle of the UK population of frogs and toads? These amphibians are already diminishing rapidly in number and a further possible threat to their survival by a proliferation of noise disturbance could lead to their virtual extinction.

Thunderstorms emit low frequency noise and some species of amphibians are believed to react to the sound perceiving it as a harbinger to forthcoming wet and damp conditions and venture forth to breed.  This has been particularly noticeable amongst the spadefoot toad (Scaphiopus couchi), which is not native to the UK but inhabits arid regions of the South-western United States.

Experiments have shown that by revving a motorcycle at around 95dBA these toads leave their burrows and make an assumption that it is time to mate.  Should this occur when no damp or wet conditions exist the effect upon their population would be deleterious.

British species of amphibians all tend towards winter hibernation or dormancy and have been recorded emerging to breed earlier than ever before, with a reduction in success rate.  This change in habit is believed to be due to the milder, wetter winters of recent years as opposed to the previously colder, dryer conditions.  If the ‘wake-up’ call was also partially dependent upon thunderous conditions then could year round emission of low frequency noise from anthropological sources also be playing a confusing part?

Reptiles such as snakes and lizards appear to rely more heavily upon chemoreception (‘smell’ via ‘taste’ through air sampling) rather than sound coupled with vision for survival purposes.  Nevertheless it seems they are sensitive to low frequency noise and infrasound.  Both Grass Snakes and Adders react to vibration and the former inhabit damp places often entering still water and small streams or rivers in search of prey.

Studies of the Mohave fringe-toed sand lizard (Uma scoparia) in California show it has ability to hear low-intensity, low frequency sounds (Brattstrom and Bondello 1983). Laboratory tests using dune buggy engine recordings at 95dB representative of such a vehicle at 5metres distance from the lizards showed all the creatures exposed to the noise for 510 seconds suffered actual hearing loss.

Shallow burial in the sand was not considered an adequate escape from the sounds and it was felt that exposure to noise of this intensity during the breeding season would have adverse biological effects. A recommendation by Bondello et al. was all unnecessary disturbance from mining, repeated low level jet over-flights and gunnery should be restricted from the immediate area of the dune systems inhabited by the lizards.

The British sand lizard is restricted in habitat and as such is an endangered species appearing mainly in areas of fairly highly classified nature conservation. This does not mean they are completely protected from such eventualities as road building or wind farm erection and could easily fall foul of noise disturbance from such projects. Without proper studies into the effects of low frequency noise and infrasound upon both the habitats and their vulnerable inhabitants what damage might ensue?

Moles live almost exclusively underground. A study in 1978 (Konstantinov) showed that these small mammals (from a group of 30 species of insectivores) had hearing of the lowest frequency and relatively high thresholds. Tests denoted that sound levels of 90dB and above caused mammals to retreat from the sound source, freeze and display a strong startle response, but not necessarily in that order. Sound levels below about 90dB usually caused much less adverse behaviour.

Unfortunately the Hz level of the test noises is not known, but the behaviour pattern is indicative of what might be expected if a wild creature is suddenly faced with the uncertainty of danger from the source of an unexpected noise.

Vocalizations of prey species are sometimes pure-toned calls, which are more difficult to locate than multi-frequency calls. Vertebrates do not locate all pure-toned sounds with the same accuracy. In a controlled test, Isley and Gysel (1975) determined how well nine red foxes (Vulpes vulpes) located 13 different frequencies of pure sound, varying from 300Hz to 34kHz.

Using food as a reward, the foxes were trained to choose the correct location of a 74dB sound signal emitted from one of two possible loudspeaker positions. The foxes located the sound source best from 0.9 to 14 kHz (<90% accuracy) with a slight decrease in accuracy at 8.5kHz (84% accuracy).

They had the most difficulty locating the source at 0.3, 0.6, 18, and 34 kHz (<78% accuracy). Foxes appear to readily locate a wide range of sound frequencies and may have maximized their chances for locating certain calls, which are presumably difficult to locate.

Precise results at the lowest frequency sound (300Hz) utilised are not known, but as included in the least successful bracket for location accuracy lead to the probable conclusion, as might be expected, that use of low frequency or infrasound plays little or no part in hunting/feeding activities. Thus it might be surmised very low frequency sound could be disturbing as the animals would be unable to identify it.

In another experiment audiograms were obtained for two least weasels (Mustela nivalis), using behavioral methods. The hearing range of the least weasel for intensities of 60dB SPL extends from 51Hz to 60.5kHz, with a region of best hearing extending from 1kHz to 16 kHz (Heffner and Heffner 1985). Hearing in the least weasel appears to be similar to other members of the order Carnivora for which data are available.

The high-frequency hearing ability of the least weasel lends additional support to the relationship between functional inter-aural distance and high-frequency hearing, whereas its sensitivity to low frequencies in the absence of obvious morphological specialization of the middle ear makes the least weasel unusual among the small mammals (although not unique as shown with the ferret in the chart on page 21).

Infrasound and LFN effects upon invertebrates do not seem to have been extensively studied, but some mixed findings are interesting. Frings and Frings (1959) reported that flies of the order Diptera showed a startle response at 80-800 Hz (at 80 dB) and at 120-250 Hz (from 3-18 dB above ambient levels). However, the long-term responses to these sounds are not given.

Earthworms have been shown to move toward the surface near roadways at low frequencies (5 Hz) exposing them as a food source for birds. Worm charming competitions have indicated that repeated beating of an earth patch will bring the creatures to the top. This might pose a problem for birds if worms are raised by LFN from sources such as wind turbines by attracting them into areas swept by revolving rotor blades.

Some studies have been undertaken with regard to the use of noise as a deterrent to insects. These have not been particularly successful as sound exposure to even large numbers of insects has been difficult to interpret. Interestingly however Honey bees (Apis mellifera) ceased moving for up to 20 minutes in response to frequencies between 200 and 2,000Hz with intensities varying from 107dB to 119dB (Frings and Little 1957; Little 1959) and did not appear to habituate to the sound.

Conversely midges (Chironomidae) exposed to 125Hz at 13 dB – 18dB above ambient noise caused increased movement to the extent of acting as a possible attractor (Frings and Frings 1959). This may go some way towards explaining why insects seemed to have been attracted to wind turbine blades to such an extent as to reduce power generation[22].

By now it will be apparent that emission of noise clearly poses problems but also many unanswered and possibly unanswerable questions in relation to the affects upon wildlife. In order to go some way towards seeking at least a partial solution to some of the queries raised we must establish the known output of infrasound and low frequency noise from a variety of sources that are likely to be encountered by land-based and freshwater creatures.

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[22] Nature Magazine Vol.412 5th July 2001

## SOURCES AND EXAMPLES OF LOW FREQUENCY AND INFRASOUND DISTURBANCE

We know that Elephants and Whales make use of infrasound for communication, as do Rhinoceros, Hippopotamus, Giraffes and Okapi. Alligators take advantage of the conductivity of water to send low frequency sounds to attract a mate and migrating birds use turbulent airflow from mountain ranges as navigational aids.

Land-based mammals in the UK are not believed to use low frequency sound or infrasound for hunting, communication or attracting mates. Where sound is of importance it is usually at the other end of the range, such as with the use of ultrasound by Bats. Yet they are still susceptible as recipients of the lower sound ranges being able to detect them through hearing and nervous systems.

British freshwater fish however, are similar to many of their counterparts in the sea and some fish adapt to both environments, albeit in a limited capacity (estuarine inhabitants and eels for example). Consequently infrasound plays a part in finding food, avoiding predators and choosing mates.

Comment has already been passed on the effects of sonar-generated sounds on marine life including fishes. Other studies have been made in relation to low frequency sound and fish. The following are extracts from some of the published reports of the general effects of underwater noise on fish:

- When marine fish were exposed to sound pressure levels 40-50dB above that in their normal environment (at 40Hz – 1000Hz) severe problems occurred; the viability of fish eggs was reduced and growth rates for fry were significantly reduced. (Banner and Hyatt, 1973)
- A broad band, 140dB sound applied to fish tanks for 20 minutes a day influenced fat stores, growth and reproductive indices. (Meir and Horseman, 1977)
- Studies show harmful effects of even moderate noise on hearing in fish. (Myrberg, 1980)
- As background noise increases, fish hearing decreases. (Myrberg, 1980)
- Intense noise levels (180dB) destroy the hair cells of the auditory maculae resulting in hearing loss. (Enger, 1981)

Mention has also already been made of a report by Lagardere in 1982 that confirmed shrimp reared under sound levels 20dB – 30dB above ambient noise showed significantly reduced growth and reproductive rates, decreased food uptake and increased mortality.

There are freshwater shrimps as well as the marine variety and both serve as an important part of the food chain with many fish preying upon them. In the event that relatively low levels of sound affect their life cycle this could impact seriously upon the predators as well.

Earthquakes, volcanoes, tidal waves and hurricanes are just some of the more extreme sources of natural infrasound. Although the consequential loss from the physical damage can be disastrous the events are not necessarily continuous at any one location and are usually relatively short in duration.

Occasionally a man-induced event will produce brief but tragic results that are recorded by sound monitoring devices. One example was the re-entry of the Space Shuttle Columbia in February 2003 when the sonic booms and subsequent disintegration of the craft were registered.

Prior to satellite monitoring the method of seeking the source of nuclear explosions was by seismic recording of infrasound and of course nuclear blasts are a prime example of infrasound created by human activity.

On the other hand low frequency sound and infrasound created by humans can be transient (shipping, lorries, trains etc.), intermittent (shot blasting, pile driving etc.), as well as virtually permanent and unremitting (wind turbines, oilrigs, pumping stations etc.).

There are many examples of man-made sources of low frequency sound and infrasound and some are included below:

**Wind Turbines**

Wind turbine manufacturers publish detailed performance reviews of their equipment and normally include noise levels as part of the specification. The sound is measured at source and usually relates to that emitted by the hub at a fixed point above the ground (or sea) and at a selection of wind speeds.

The wind speed is important as the higher the speed the faster the turbine blades are driven and a safety cut off point is inbuilt. Otherwise the turbine on its tower could become unstable.

Wind turbines are designed to operate where it is windy and that includes areas on land and off shore. In both cases the turbine tower has to be secured to a stable base and it is through the base that some sounds are transmitted as well as from the blades and at the height of the nacelle or hub.

Consequently if a turbine is located on land upon a base of concrete inserted below ground level, sound will radiate from the base. This will occur either by transmission from operation of the sails through the fabric of the tower into the footings or as the result of vibration of the construction on its foundations.

Additionally any noise from the bearings in the hub or from revolving blades will also permeate the air.

Should the turbine be placed close to water, such as near to a small pond or reservoir then low frequency sound and infrasound could conceivably travel via the ground into the water. Likewise the sounds conveyed in air would also impact upon the water and as has been commented upon already the effects of differing conductive mediums are considerable.

A lot would depend upon the distance of the turbine from the water and the make up of the surrounding earth plus the presence of any other structures, vegetation or intervening force such as change in wind direction as all could vary the level and direction of sound.

A Danish manufacturer of wind turbines (Bonus Energy) was contacted and they provided the following data in relation to a 1.3MW turbine with different hub heights above ground: -

| Hub Height Above Ground | Wind Speed at 10metre Height | Sound Power Level at +/- 2dB(A) uncertainty | Measurement Distance From Turbine |
|---|---|---|---|
| 45 Metres | 8 Metres Per second | 98.9 dB(A) | 70 Metres |
| 60 Metres | 8 Metres Per second | 102 dB(A) | 70 Metres |

Note the sound power level increases with hub height and no figures were supplied for low frequency or infrasound recorded.

The 60metre tower was described as being of conical, tubular construction enclosed in a steel canopy with 29metre blades producing a diameter of 62metres. The blades revolve at 13 – 19rpm over a swept area of $3000m^2$. The tower is hollow with internal platforms spaced to enable ascent without additional safety harness.

The tower, being hollow might produce a Helmholz effect (resonance) thus adding to low frequency sounds instigated by operation of the blades, although this is not mentioned in the literature containing technical data about the turbine mentioned above. Noise would also arise during construction of foundations, erection procedures and servicing.

Underwater turbine noise is not usually included in the manufacturers specification. Obviously if a turbine were located at sea or in a large lake the water bourn sound would differ from its counterpart travelling exclusively in air and be different again from a combination of conductive mediums.

Here are some report findings[23] relating to underwater noise recorded in a study of off-shore turbines:

| Turbine Type | Wind Speed (m/s) | Source Level (dB re 1μPa$^2$/Hz) | Noise Frequency (Hz) |
|---|---|---|---|
| *Middlegrunden, Denmark* | 13 | 115 | 125 |
| 20 x 2MW 'Bonus' turbines | 6 | 101 | 125 |
| concrete foundation | 6 | 111 | 25 |
| *Bochstigen-Valar, Sweden* | 8 | 108 | 160 |
| 5 x 0.55MW 'windworld turbines | 8 | 108 | 16 |
| steel monopile | | | |
| *Vindeby, Denmark* | 13 | 113 | 125 |
| 11 x 0.45MW 'Bonus' turbines | 13 | 130 | 25 |
| concrete foundation | | | |

Notice how the dB levels increase with wind speed and from the larger (MW) turbines, also that the low-level Hz frequencies do not always coincide with higher dB output. In fact the peak noise was 130dB at 25Hz. Only one recording (16Hz) was at infrasound level or below but all others were at low frequencies.

More noise came from turbines on concrete foundations and the result recording a 130dB level was sufficient to reach the pain threshold for humans if emitted in air.

Other noise associated with installation of turbines is pile driving, which can reach source levels of between 150 –230dB and radiate in water up to 20KM (12.5miles). Vessel traffic would also produce additional noise during the construction phase and service or repairs.

The report concluded that physiological and behavioural effects would occur in sea creatures from the effects of underwater noise and vibration caused during installation and operation of wind turbines. In particular displacement both temporary and permanent would occur with habitat fragmentation.

When considering the effects of land-based wind turbines upon freshwater fishes or mammals frequenting a watery and waterside habitat, the level of the sound measurements taken from the generators subjected to the above study are significant.

Clearly quite high dB levels are transmitted and could travel long distances. We know from turbine manufacturers own recommendations as well as other sources that turbines should not be erected close to human dwellings. Why then should they be permitted where other creatures live?

According to the WHO Guidelines for Community Noise 1999, "The annoyance inducing capacity of a noise depends mainly upon its intensity and spectral characteristics, and variations of these with time". The report writers also commented, "It should be noted that a large proportion of low frequency components in the noise may increase annoyance considerably". And goes on to say, "Where prominent low frequency components are present (in noise) they should be assessed".

Presumably annoyance to creatures other than man would also occur if exposed to the same source. The difference being that what transpires to be a nuisance to humans might be a matter of life or death to an animal or fish because of interference with habitat.

Another more recent report was published by DEFRA[24] and concluded, "There is no doubt that some humans exposed to infrasound experience abnormal ear, central nervous system, and resonance induced symptoms that are real and stressful. If this is not recognised by investigators or their treating physicians,

[23] The Humane Society of the US
[24] A Review of Published Research on Low Frequency Noise and its Effects, Dr G Leventhall 2003

and properly addressed with understanding and sympathy, a psychological reaction will follow and the patient's problems will be compounded. Most subjects may be reassured that there will be no serious consequences to their health from infrasound exposure and if further exposure is avoided they may expect to become symptom free".

Three basic points arise here but before raising them it should be understood Dr. Leventhall who led preparation of this report did write separately following the issue of same to emphasise that in his opinion wind turbines did not emit infrasound at sufficient levels to cause any problems at all to humans.

Returning to the points arising. Firstly any 'real and stressful symptoms' suffered by humans would also be incurred by other creatures exposed to the same source(s) of sound(s). Secondly the resulting 'psychological reaction' in humans, if repeated in other creatures would be impossible to treat by reassurance. Thirdly avoidance would be impossible by fishes and other aquatic life trapped in ponds etc.

Regarding the subsequent assurance regarding noise from turbines it does not seem that anywhere in the report were sound measurements secured from underwater or any attention given to the effects upon creatures other than humans. The latter would of course be expected as the report was only concerned with how people might be affected.

According to Bel Acoustic Consulting in their report of June 2004 for the Energy Efficiency and Conservation Authority in New Zealand the sound power level of a typical wind turbine in the 16Hz one-third-octave band is around 105dB at a wind speed of 10mps. The report says, "This means that the sound pressure level at only 100metres distance will be in the approximate range of 50dB to 55dB and this is far lower than the audibility threshold of around 85dB for this low frequency sound".

Unfortunately the wind does not always blow at 10mps and as can be seen from the findings of the Humane Society of the US shown on the previous page both higher and lower wind speeds can produce greater levels of sound. Moreover infrasound as we have seen does not have to be 'heard' to cause unpleasant symptoms in humans and marine mammals and whilst people might not be encouraged to live 100metres from turbines other creatures may not have that luxury.

The Department of Trade and Industry (DTI) have produced public information about renewable energy sources that is freely available from their web site[25] and embraces considerable space explaining the noise produced by wind turbines.

According to the DTI if a turbine produces a sound power level of 104dB(A) then installation of a second turbine with the same power sound level will only cause an increase of 3dB(A). Yet they admit a sound level of 100dB(A) contains twice the energy of a sound level of 97dB(A) and increasing the energy of a sound by 26% raises the noise power level by 1dB(A) or tripling the energy of a sound yields an increase of 5dB(A).

Despite using the above figures as examples it should be noted that elsewhere in the DTI information they indicate modern wind turbines emit sound up to 106dB(A). They also take pains to explain how distance reduces the perceived level of sound and the noise from a wind turbine can reach moderate sound pressure levels (less than 50dB(A)) when the distance from the turbine is between 200 and 300 metres.

According to the DTI most proposals for installation of wind turbines are assessed using the sound limits of 35 – 40dB(A) at the nearest dwellings occupied by those without a vested interest in the project. In other words they should be situated further away than the 100 metres mentioned in the Bel Acoustics report and the 200 -300metre distance shown in the above paragraph.

The lowest levels are stipulated for 'night noise' so as to try and avoid sleep disturbance. Clearly the 'noise' would be unacceptable any closer whether emitted during day or night and must surely also be intolerable to other creatures, especially those unable to escape from the vicinity.

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[25] www.DTI.gov.uk

Another report has been issued by the UK government and published as an accompanying document to Policy and Planning Guide 22 (PPG22) from the Office of the Deputy Prime Minister (ODPM). The accompanying document is over 180 pages long and relates to guidance for various forms of renewable energy projects.

In respect of wind power, paragraphs 45 and 46 in the technical annexe refer to Low Frequency Noise (Infrasound) and insist, “There is no evidence that ground transmitted low frequency noise from wind turbines is at sufficient level to be harmful to human health”.

Reference is made to a technical report[26] issued in 1997 on behalf of the DTI which says a comprehensive study of vibration measurements at a modern wind farm was made with measurements being taken on site and up to 1km away in a wide range of wind speeds and direction.

They stipulate the study found that:

- Vibration levels 100metres from the nearest turbine were a factor of 10 less than those recommended for human exposure in critical buildings (i.e. laboratories for precision measurement).
- Tones above 3.0Hz were found to attenuate rapidly with distance – the higher frequencies attenuating at a progressively increasing rate.

The measurements were clearly land-based and seem not to have been taken at the foot of the turbine(s) and then progressively further away but utilise a starting point 100metres distant from the source. More importantly it should be remembered that in 1997 wind turbines were considerably smaller than those currently being erected and therefore required foundations commensurately smaller.

This poses the following questions:

- Why are the DTI relying upon findings from a report almost a decade old?
- Has another report been commissioned on a site with larger and more turbines in situ?
- Surely the measurements should start from as close to the turbine base(s) as possible?

To be reasonably certain that the infrasound from land-based turbines does not affect creatures other than humans the proposed sites should be surveyed in detail for other life forms before construction work commences. Then monitored during erection and operation of the turbines in accordance with international requirements (Berne Convention recommendations[27]).

The French National Academy of Medicine[28] has suggested low frequency noise from wind turbines produces a reality of health risk to humans. They recommend (until alternative proof is found) that installation of wind turbines in excess of 2.5MW capacity should not be closer than 1.5km from occupied houses.

The reasons cited are that considerable information was presented at an international conference on wind turbine noise held in Berlin in October 2005 as well as inter alia, noise evaluation surveys at a French wind plant.

Another recommendation by the academy is to conduct two studies to prove whether noise from wind turbines is harmful. First they suggest turbine noise levels inside houses should be recorded over a time period and secondly health effects properly monitored.

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[26] ETSU W/13/00392/REP

[27] The Bern Convention on the Conservation of European Wildlife and natural Habitats (the Habitats Directive)

[28] Reported in Wind Power Monthly, June 2006

Once again it is understandable why no mention is made of any attempts to measure problems that might be caused to other animals, as the academy is concerned with human medicinal matters. Logically if such noise does impact upon human health it will also affect other creatures, not forgetting if a safety distance of 1.5km applies to people, many other creatures within that band would exist.

The French national Renewable Energy Syndicate (SER) and the French Wind Energy Association (FEE) were not consulted by the academy. They point out their own study has found noise emissions from turbines reach 100dB at rotor height, 55dB at the foot of the tower and 35dB at a distance of 500m. These are generalised findings and are not specific to infrasound levels.

In July 2006 New Scientist magazine issue 2559, carried an article (page 36) that referred to information in another journal[29] by Andrew Gill from the Institute of Water and Environment, Cranfield University. He pointed out a mere 1% of all papers on renewable energy published in the past 15 years considers environmental impacts of wind turbines onshore and none offshore. Highlighting the paucity of ideas of how offshore installations will affect the marine environment and disrupt its wildlife through habitat damage, noise and vibration, electromagnetic fields and collisions with turbines.

Gill points out the marine ecosystem is largely uncharted territory, so wind farm developers often have no way of knowing which sites might be less vulnerable. The same can almost certainly be said of some similar onshore areas, especially those with territories of mixed land and freshwater.

The problem with renewable energy generators particularly wind turbines is where to put them. Mark Avery of the Royal Society for the protection of Birds (RSPB) is in agreement and whilst the organisation welcome technology with the potential to combat climate change they have very real concerns at both the damage they (wind turbines) cause to birds and lack of studies on the subject in countries who embraced wind farms years ago.

Examples of noise from wind farms and the apparent problem caused to animals are sometimes reported and once again New Scientist magazine carried a brief article[30]. Lawrence Rabin of the University of California and his colleagues compared the behaviour of two groups of Californian ground squirrels in similar environments, except that one group lived close to a wind farm.

Recordings of alarm calls were played to each squirrel group. Those living near the turbines were more likely to dash back to their burrows upon hearing the calls and spent more time looking for predators. The study team felt the turbine noise increased the squirrels' alertness, perhaps because of the need to compensate for their reduced ability to communicate through sound.

Enforced behavioural change could have considerable causal chain effects. The squirrels are a food source to predators such as the golden eagle and an acute rise in alertness might reduce the kill rate. This could lower the breeding success of the birds with a resultant reduction in population. The squirrels might also breed less being unable to feed as often leading in turn to fewer being available as prey.

The squirrel burrows are also used as homes by red-legged frog and California tiger salamander. A decreased squirrel population would lead to a shortage of 'dwellings' through habitat loss with in turn, further inevitable changes to the population of those species.

The researchers felt wind turbine noise may affect wildlife communities all over the world. Consequently they consider more care needs to taken over choosing where to site them.

A suggestion that turbine noise disguises danger was the subject of an in depth study in 2002 by R Dooling, Ph.D of the United States National Renewable Energy Laboratory (NREL)[31]. The report focussed upon the hearing capability of birds as a reason for high bird mortality rates following collisions with wind turbines.

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[29] The Journal of Applied Technology – 2005 (Vol 42, page 605)
[30] New Scientist magazine, issue 2549 3 May 2006 (page 21)
[31] NREL/TP-500-30844: Avian Hearing and the Avoidance of Wind Turbines, June 2002

According to the findings birds in general hear best between about 1kHz and 5khz. The report dispelled as myths the suggestion that birds hear better at high frequencies than do humans or other mammals and that birds have exceptionally acute hearing. Stating that ‘ when hearing is defined as the softest sound that can be heard at different frequencies, birds on average hear less well than many mammals, including humans.’

A selection of data on bird hearing was utilised including audiogram plots from 49 species showing the hearing capabilities in the quiet and a selection of those species were plotted showing how they hear in noise. The difference between ‘quiet’ and ‘noise’ being important because of the masking features of the latter and relevant to windy conditions required to drive wind turbine blades.

The conclusion was that birds probably couldn’t hear the noise from turbine blades as well as humans can. In practical terms it is suggested a human with normal hearing can probably hear a wind turbine blade twice as far away as can the average bird.

Wind noise and sounds emitted by wind turbines are mainly low frequency and measurements taken and utilised by the report writer were almost all recorded at a sound pressure level (SPL) of 65dB(A) at frequencies below 1kHz – 2kHz. They discovered that due to some blade defects some turbines whistled and concluded this might help birds avoid turbines.

Adding a whistle emitting an acoustic sound within the hearing range of birds (2kHz – 4kHz) would add almost nothing to overall SPL but might help birds hear the blades. It is believed that as birds approach a wind turbine, especially under high wind conditions, they lose the ability to see the blade (because of motion smear) before they are close enough to hear the blade.

The report hypothesises that louder (to birds) blade noises might result in fewer fatalities. A test by making noise measurements and comparing fatalities at turbines with noticeable whistles with those having no whistles was mentioned but does not appear to have been done.

In compiling the report the various bird species from which avian audibility curves were secured predominantly arose from studies made over the preceding 50 years (39 species) with another 10 that included data from physiological recordings. Birds were typically tested at frequencies between 0.5kHz – 10kHz although not all were tested at exactly the same frequencies.

The birds were subdivided into groups. Passeriformes (songbirds, perching birds), non-Passeriformes (including game birds, falcons, waders, pigeons, emu and parrots) and Strigiformes (nocturnal predators like owls). In general the opinion was there was less variation in hearing sensitivity among birds than among members of other vertebrate groups.

The findings denoted that nocturnal predators detect softer sounds in general than either of the other two groups over their entire hearing range. Indeed the absolute auditory sensitivity of birds, such as the barn owls are unusually low, probably because of their predatory nocturnal lifestyle. (Konishi 1973, Van Dijk 1973, Dyson, Klump and Gauger 1998).

On average, the spectral limit of ‘auditory space’ available to a bird for vocal communication extends over a bandwidth of 0.5kHz – 6kHz. A particular exception being the common pigeon, which is believed to have an unusual auditory sensitivity to very low frequency sounds (Quine 1978; Yodlowski 1980).[32] Some estimates denote they are almost 50dB more sensitive than humans in the frequency region of 1Hz –10Hz (Kreithen and Quine 1979).

According to Dooling, birds are unusual among vertebrates in the remarkable consistency of their auditory structures and in their basic hearing capabilities, such as absolute thresholds and range of hearing. Yet the auditory curves published in the report display differing ranges. These might arise through difference in species size with constraints imposed on low frequency sensitivity in small birds due to body size.

[32] These findings were not included in the chart compiled earlier in this paper (page 18).

Dooling also says that compared to most mammals, including humans, birds do not hear well at either high or low frequencies. Even allowing for the exceptions previously mentioned (pigeons and owls) there are no cases in which birds hear at frequencies higher than about 15kHz. Neither do they generally hear as well as mammals and humans at low frequencies.

Consequently he concludes as most of the energy generated by wind turbines is at lower frequencies (less than 1kHz – 2kHz) this means even in the quiet, a bird would need to be much closer to a turbine in order to hear it, than a human. For example, the human threshold at 1kHz is about 5dB SPL and the average bird threshold at 1kHz is about 20dB SPL.

When the turbine noise is masked and even at night in rural areas there is always some background sound, it needs to be at least 1.5dB above the background noise to be detected by birds. For humans a noise need only be about 0.5dB greater than the background to be 'heard' above the ambient sound.

In order to further research into the masking effects Dooling pursued the effect of noise on signal detection and investigated detection of tones in noise. He found no direct field data available for the former and relied upon laboratory-controlled information to provide estimates. Regarding the latter he obtained critical ratio data behaviourally for 14 species of birds including songbirds, non-songbirds and nocturnal predators.

These species were plotted on a graph. For 11 of the 14 species (which he plotted as an average) he found a signal in the region of 2kHz – 3kHz must be 26dB – 28dB above the spectrum level of the noise to be heard. This average curve follows quite closely the typical pattern of a 2-3 dB/octave increase in signal to noise ratio that is characteristic of these functions in mammals, including humans.

In both mammals and birds, this orderly increase is related to the mechanics of the peripheral auditory system (Behesy 1960; greenwood 1961; Buus, Klump, Gleich and Langemann 1995). Three exceptions however, occurred among the 14 birds, namely the budgerigar, barn owl and great tit.

What the curve described in practical terms is the level in decibels above the spectrum level of the background noise that a pure tone must be in order to be heard. For the average bird it was as described above but not in the case of the three excepted birds mentioned. For the human, the same pure tone need only be about 22dB above the spectrum level of noise to be heard. This represents a difference in masked thresholds of 6dB

In essence because of the inverse square law that applies when measuring sound from a fixed source over a distance, the difference represents approximately a doubling of distance. (Sound decreases as it travels away from the source and a human can still detect a sound in noise at twice the distance a typical bird can).

Noise can of course mask another noise just as it does when masking a tone. Adding noises together (dB plus dB) does not simply increase the sum of the noises, i.e. adding two 60dB SPL noises does not result in a single noise (tone) of 120dB SPL. Neither can adding energy at a single frequency in a broadband of noise simply rack up the total. This is due to energy being summed across the entire noise band being emitted. Thus increasing a single frequency by say, 2kHz only increases the overall noise marginally.

Experiments have been carried out to determine how much a level needs to be increased to be detected by humans. In 1947 Miller discovered it has to increase about 0.5dB – 1dB. Similar data exists for three bird species, the budgerigar, the starling and the barn owl (Dooling, Lohr and Dent, 2000). All three were shown to hear about a 1.5dB change in level of flat, broadband noise. Once again acoustically their discrimination is less than for humans.

Dooling did further research by measuring sound at a wind farm (which is how the whistling effect was discovered) using a reference point 10m (33ft) from the tower. The SPL was recorded including wind noise and turbine blade noise at about 70 dB (A). The ambient noise was constant but as to be expected the turbine noise decreased with distance until at 25m (82ft) from the base of the turbine the blade noise was less than the background noise.

At this point the blade noise would be inaudible to birds, based upon the previous figures. Higher and lower ambient noise levels have a dramatic effect on the hearing distance. If noise increased 10dB to 80dB(A) SPL the blade noise would not be audible to a bird until it was within less than 10m (33ft) of the blade.

The three unrelated species, budgerigar, starling and barn owl all had a value of 1.5dB for detecting noise in noise and it is likely this holds true for all birds. This would represent a clear hazard for all flying birds. Higher ambient noise would arise with higher wind velocity and 80 dB (A) is quite typical so if higher than this the detection distance level of blades by sound would fall further with attendant collision risk. (Note 70dB (A) is considered normal for mild to moderate wind velocities).

Sound and vision normally work in concert. Painting wind turbine blades with different patterns might be thought to aid a bird to see them before hearing the noise and being alerted to the danger. Yet because the two senses invariably work together this might not work and of course the visual aspect is confused by the smear factor that renders the blades invisible to a flying bird.

Being unable to see or hear the blades represents a very real danger and probably explains the high mortality rate at wind farms sited in frequently used flight or migration paths. The down draught and turbulence caused by the wind passing through the blades also plays a part in disturbance, injury and death rates.

Under the UK Department of Trade and Industry Sustainable Energy Programmes a report was commissioned and first published in 2001 assessing the effects of noise and vibration from offshore wind farms on marine wildlife[33].

No similar report exists covering these effects upon land based wildlife as presumably it was not considered that detrimental exposure would be caused by clearance and site preparation or the operation of wind turbines on land, even if close to freshwater sources containing aquatic creatures. Generally it seems for land sites an ecology statement is produced by the proposed developer either voluntarily or more frequently in the form of an Environmental Impact Statement.

There are however some interesting observations contained in the marine report that could equally or partially apply to fresh water fishes and invertebrates starting with the generic impacts of building a wind farm and these are:

- Characterisation of noise and vibration generated by (offshore) turbine operation and construction activities.
- Propagation and attenuation of noise and vibration above and below the surface.
- Prediction of noise levels (at the shoreline) and impacts on (marine) wildlife.
- Likely range background noise above and below the surface.
- Identification of noise sensitive (marine) species most at risk to noise and vibration impacts related to UK (offshore) wind farms.
- The effects of noise and vibration on (marine) species.
- The extent to which (offshore) wind turbines may provide physical protection and new habitat opportunities.

The site sizes were to be restricted to $10km^2$ and contain up to 30 turbines on each with a minimum output of 20MW (assumed generating capacity rather than actual production).

In summary the report concludes that ocean noise from wave, wind, rain and so on is produced across a very broad array of frequencies ranging from 1Hz – 25Hz with source levels up to 100dB. (They do not state whether this source was air or water bourn or a mix).

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[33] ETSU W/13/00566/REP – University of Liverpool, Centre for Marine and Coastal Studies etc.,

It confirmed noise and vibration from human activities in the ocean are generally mid-low frequency between 10Hz and 1000Hz from such things as shipping, transportation, dredging, construction, hydrocarbon and mineral extraction, geophysical survey, sonar, explosions and ocean science studies.

Furthermore these operations may have very high source levels e.g. geophysical and seismic surveys at over 200dB and are both of brief (transient) or long (continuous) duration with generation including pulse, explosive or drilling. Wind farm operation noise is expected to fall within the 'continuous' category.

This is interesting because the range of noise and vibration and many of the sources would also apply to erecting and operating large land based wind turbines and could easily impact upon inland creatures, particularly fresh water fishes.

With regard to fish the report indicates they produce underwater sounds through stridulation (rubbing together body parts) and manipulation of the swimbladder, with frequencies produced ranging from 50Hz to 5kHz and source levels of up to 140dB. Whilst admitting that the sounds produced by many fish are not fully understood the report postulates that stridulatory noises are thought to be associated with alarm and resonant swimbladder sounds may play a role in social communication.

Clearly the noise from wind turbines has a frequency range coinciding with those made or utilised by fish and the report admits this overlaps with the sensitivity thresholds of many fish and some of the larger marine mammals. Reference is made to information taken from the study of an offshore wind farm at Svante, Sweden where the estimated peak noise was 120dB at 16Hz and mentioned some effect may be apparent on species such as cod.

One of the report conclusions is that due to the lack of available studies into the effects of offshore wind farms upon mammal, fish and migratory fish behaviour and ecology further monitoring is needed and additional studies required.

Nevertheless mention is made of other studies concerning fish (and these are not named) showing that noise in general, such as that associated with shipping, causes avoidance that can lead to change of migration routes, feeding and spawning areas. Obviously an inference that arises is if this occurred at sea then similar general noise could affect fish within pockets of landlocked water. Unfortunately having less room to take avoiding action might have greater adverse consequences.

The report also avers to the lack of study describing the impacts of noise on invertebrates and planktonic organisms but suggests the general consensus is that there are very few effects, behavioural or physiological, unless the organisms are very close to a powerful noise source.

This seems rather a summary dismissal of what could be a significant effect by noise from turbines upon important levels in the food chain. Presumably peak noise sources of 120dB are not deemed 'powerful', which maybe true when compared with airguns at >200dB, but would surely still be considerable when up close?

A couple of intriguing aspects arise in the report summary. The first suggests that as well as fish taking avoiding action when confronted by constant noise some also seem attracted to the source. Whether this is because of disorientation or simple curiosity is not discussed. Possibly they believe the sound has uncovered a fresh food source, as this must surely occur following a heavy storm or even tremors and the like from earthquakes.

The second intrigue is that building and inserting a number of large wind turbines into the sea could create new habitat for wildlife from artificial reefs. Likewise perhaps on land except here it would be a change of land use beneath the turbines as opposed to creating constructions for the adherence of barnacles and the like.

Apparently fish tend to congregate around objects placed in the sea although the report says the reason is poorly understood and it is postulated they are attracted as submerged objects provide shelter from currents, wave action and predators. Another reason maybe weed growth containing food sources.

Oilrig platforms seem to act as a magnet for some creature species despite noise from pumping operations. Possibly wind turbines in the sea would act similarly, although it appears a higher level of more or less continuous noise may be somewhat of a deterrent. Only time and study will confirm one way or the other.

Interestingly Beulig (1982) demonstrated that sharks are attracted most readily by broad-band, low-frequency, irregularly pulsed sounds of 20-100 Hz. To investigate the possibility that sharks are attracted to biologically significant sounds (such as accelerating schools of fish, injured and struggling fish, and feeding animals) that exist in the frequency range below 20 Hz, Beulig measured the responses of juvenile lemon sharks (Negaprion brevironstris) to low frequency (12.5 Hz), irregularly pulsed sounds.

The sharks were born in captivity and deprived of normal prey-capturing experience and social interaction with wild sharks. Initially, the juvenile sharks, tested individually, were not attracted to the low-frequency sounds, even after opportunities to capture living prey and to experience auditory stimulation associated with wounded, struggling fish were provided.

When the sharks were tested in groups of three, their approach-response level indicated attraction to the low-frequency sound and results compared favourably with juvenile sharks that had species-typical feeding and rearing experience. Thus, the existence of a social factor in response to sounds was verified.

Mindful of the current intention to place a large number of wind turbines in the shallow seas surrounding the coastline of Great Britain coupled with increased sightings of various shark species in coastal waters one wonders where this might lead.

**Motor, Rail and Air Traffic including Sonic Booms**

How noisy is a large lorry? This will depend upon many factors including weight and type of load, whether the vehicle is under stress climbing a gradient, which gear is being utilised, what type of road surface it is travelling on and where the receiver of the noise is situated in relation to hearing the sound.

Road traffic by its very nature does not stand still for long. The noise of a single vehicle is therefore not necessarily as critical as the volume of traffic and frequency times. Naturally limiting the noise of individual vehicles at the point of manufacture will assist in reducing the combined sounds from a large number travelling in streams or convoys.

The European Parliament set a noise limit for heavy lorries that was introduced by the European Community in 1992. The level agreed was 80dB(A) across the board although some individual countries opted for slightly differing arrangements, such as Austria where a night travel (10pm – 5am) ban already applied to lorries on motorways unless exempt. Here the exemptions set a limit of 78dB(A) for lower powered lorries and 80dB(A) for the larger variety.

This Parliament also set limits for cars at 77dB(A) falling to 74dB(A) after 1996 and for motorcycles to be reduced in stages. Since 1994 the levels for two wheeled motor vehicles have been 75dB(A) for machines up to 80cc, 77dB(A) for those between 80cc -175cc and 80dB(A) for those above 175cc.

The various levels have been adopted by the UK and under Planning Policy Guidance 24: Planning and Noise, these levels have been used to assist in determining the acceptability thresholds to be used by planning authorities when considering the effects of noise from roads on new dwellings.

A table has been created within PPG24 that also embraces noise from air traffic and railways (large diesel trains are known to emit low frequency sound and infrasound in the range of 8Hz to 100Hz not only from the engine but also through air displacement such as when entering a tunnel).

In creating the table four noise exposure categories (NEC) were compiled and should be read in conjunction with the table. They are as follows: -

A. Noise need not be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be regarded as a desirable level.

B. Noise should be taken into account when determining planning applications and where appropriate conditions imposed to ensure an adequate level of protection against noise.

C. Planning permission should not normally be granted. Where it is considered that permission should be given, for example because there are no alternative quieter sites available, conditions should be imposed to ensure a commensurate level of protection against noise.

D. Planning permission should normally be refused.

Each of these categories is for guidance only and the method of arriving at the levels is explained in the PPG24 document. The sound levels are shown in dB(A) terms. Moreover it suggests in some cases local planning authorities may be able to justify a range up to 3dB(A) above or below those recommended. The noise exposure categories (NECs) are as follows: -

| | **Noise Exposure Category (NEC)** | | | |
|---|---|---|---|---|
| **Noise Source and Hours Applicable** | **A** | **B** | **C** | **D** |
| Road Traffic | | | | |
| 07.00 – 23.00 | <55 | 55 – 63 | 63 – 72 | >72 |
| 23.00 –07.00 | <45 | 45 – 57 | 57 – 66 | >66 |

| Rail Traffic | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| 07.00 – 23.00 | <55 | 55 – 66 | 66 – 74 | >74 |
| 23.00 – 07.00 | <45 | 45 – 59 | 59 – 66 | >66 |

| Air Traffic | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| 07.00 – 23.00 | <57 | 57 – 66 | 66 – 72 | >72 |
| 23.00 – 07.00 | <48 | 48 – 57 | 57 – 66 | >66 |

Some interesting points arise out of reproducing these ‘recommended’ levels.

- On face value the unacceptable thresholds in category ‘D’ are all much lower than the recognised sound of a single 1.3MW wind turbine.
- The tables and explanatory notes within the content of PPG24 do not explain how far away from the noise source the measurements should be taken, relying presumably upon the developers and local authority to apply discretion.
- With aircraft noise the levels relate those at 1.2metres above open ground.
- The notes state that specific industrial noise levels should not be assessed by use of the tables but can be considered if contained as part of a noise mix as long as it is not the dominant noise.
- No reference is made to measurement of infrasound or low frequency sound as a separate entity.

Once more it seems reasonable to conclude that where noise levels are unacceptable for humans they must be at least equally unacceptable to other creatures exposed to such disturbance.

Brattstrom and Bondello (1983) found that off-road vehicle (ORV) noise affected hearing physiology of the desert kangaroo rat (Dipodomys deserti). Peak SPL's measured for ORV's varied from 78dB to 110dB. Dune buggy sounds were played to the animals through an amplifier to produce a sound pressure level reaching 95dB. The kangaroo rats suffered a temporary threshold shift in their hearing sensitivity. At least 3 weeks were required for their hearing thresholds to recover. Because the ears of kangaroo rats possess anatomical adaptations to promote amplification of low-frequency sounds, the rats have little means of preventing full amplification in their ears of high-intensity, low-frequency sounds of dune buggies. This could seriously affect their ability to avoid approaching predators.

Low frequency noise and infrasound effects from motor traffic upon dairy stock would presumably have an impact on milk yield and quality if subjected to frequent exposure. The following two noise experiments are revealing.

Tractor engine sound at 97 dB significantly increased the glucose concentration and leukocyte counts in the blood of dairy cows and markedly reduced the level of haemoglobin (Broucek et al. 1983).

Although not using LFN or infrasound another experiment using a tone of 1,000 Hz (l10dB) resulted in a significant increase in circulating glucosea, nonesterified fatty acids, and creatin; a significant decrease in haemoglobin; and a slight decrease in thyroxin in plasma.

High glucose level is a recognized response to stress, in this case, probably sounds. The accompanying responses were also the result of stress, and part of the neuroendocrine stress reaction. For example, release of thyroid stimulating hormone (TSH), known to affect growth rates, can be inhibited by negative feedback from adrenocortical hormones after a stress response.

Noise from road traffic does include both low and high frequencies. Vehicle movement and rate of recurrence probably cause as much disturbance to wild life as the sounds emitted. Road kill from impact is a serious cause for concern so if further harm is being caused through noise exposure the concern increases.

The foremost difficulty in summarising the effect of road noise on wildlife is the lack of concentrated studies that have directly addressed the problem. Most have been concerned with collision damage, eradication or destruction of habitat and severing of commuting routes.

Background noise from roads ranges from almost ever-present in respect of busy thoroughfares, regular but intermittent on less frequently used roads and occasional elsewhere. Each category brings its own problems.

Constant noise raises the ambient levels and could affect creatures because of the masking effect. Less frequent but regular sounds might create just enough habituation as to be dangerous and occasionally (such as in country lanes) lull creatures from hiding at lethal moments.

Road verges can act as small havens for wildlife such as butterflies and an increase in voles and field mice on motorway embankments has seemingly led to more kestrels using these areas as feeding habitats apparently oblivious to the noise and movement of traffic. Conversely a study in America showed a decline in species variety of aquatic insects in watercourses and ponds near to roads with an increased volume of traffic. Noise is believed to have played a part but the absolute cause was not determined.

On the other hand roads can act as barriers to both non-flying and flying insects. Certain beetles have declined where roads dissect their habitat. Noise, exhaust and salinity were found to be the causes. Similarly orange tip butterfly were effectively barred from crossing a large road carrying 40,000 vehicles a day, although it is not known for certain if noise played a part.

Birds and song birds in particular have to discriminate between their own and other species calls and songs. This need is an important aid to communication for mating, group bonding, feeding, danger awareness, flocking and at the other extreme, isolation for territorial requirements. Traffic noise can mask the effects of songs and calls.

Estimates have been made that bird song will attenuate at the rate of 5dB per metre for a bird 10metres above ground in an open field to 20dB per metre for a bird on the ground in a coniferous forest. Therefore any high volume noise of a virtually permanent rate, such as that caused by continuous rates of flowing traffic on a busy highway could mask attempts at communication. (Reference has already been made to similar masking by wind turbine noise).

In the Netherlands studies have been made of the effects of road noise upon some birds. Reijnen and Foppen, 1997 studied willow warbler (Phylloscopus Trachilus) and found the density of territorial males was lower at 200metres from the road than at greater distances (up to 400metres). Also, older males were more abundant further from the road. It is suggested that noise may have an important effect (predicted to have a mean of 50dB (A) at 500metres along the highway and traffic density of 50,000 vehicles a day). The dispersal of breeding males along the road was broken down subsequently into progressively increasing in zones 0 – 200metres, 200 – 400metres and a >400metres control zone.

Another study by Reijnen and Foppen in 1998 covered a variety of bird species and found 17 of 23 species studied for three years showed some negative effect of road noise (reduction in numbers) and another twelve species of passerines were found to reduce in grassland close to a busy road. Road noise of 50dB was found to be most significant at 100metres from the road and was measured at 70dB on the verge at roadside. At a density of 5,000 cars a day the reductions for most species were 12% - 56% at 100metres distance.

At distances of >100metres only the black-tailed godwit (Limosa limosa) and oystercatcher (Haematuras ostralegus) showed reduction in density. At a traffic density of 50,000 cars a day bird density was reduced 12% - 52% for all species studied up to 500metres distance. Sensitive species including waterfowl, lapwing and skylark were reduced in density between 14% and 44% up to 1500metres.

A more extensive study of 43 species of woodland birds in both deciduous and coniferous forests found that 26 (60%) showed some reduction in density adjacent to the road. Noise was the only factor found to be a significant predictor and the number of cars and distance from the road were significant factors in the number of breeding birds.

The “effect distances” were 40metres -1500metres (10,000 cars/day) and 70metres -2800metres (60,000 cars/day). There was a reduction in density at 250metres from the road of between 20% and 98%. The frequency range of road noise was 100 Hz to 10 kHz with the loudest in the range of 100-200 Hz and 0.5-4 kHz with a threshold at between 20dB (A) and 56dB (A). The authors note that if noise were constant there was no difference between plots with high and low car visibility.

It should also be noted that a supplementary aspect for the reductions was thought to be stress brought about by the noise and movement of the vehicles. Furthermore a similar study in the USA supported the findings and commented that mammals (moose and deer), amphibians as well as some species of grassland and forest birds were all affected at distances of >100metres from the roadside when traffic levels were increased to 15,00 – 30,000 cars a day. Both presence and breeding of birds was reduced up to 700metres and with more than 30,000 cars a day presence and breeding was reduced up to 1200metres away.

Quite clearly low frequency noise played a significant role in creating bird disturbance/displacement and was sufficient to cause a serious reduction in breeding numbers in the study areas. Assuming similar habitat was within reasonable distance without interference from road noise then after initial displacement successful breeding may have been achieved elsewhere. Severe problems could arise if not.

In a nocturnal species (the stone curlew, *Burhinus oedicnemus*) in England, roads were found to reduce numbers at distances of up to 3 km. The authors suggest that visual stimuli (headlights) could have a greater effect than noise alone even though traffic noise or vehicle movements are suggested as primary causes. It should be noted that, in this study there was no evidence of a lessening of the effect if nearby suitable habitat (away from the road) was scarce or abundant.

Gutzwiller and Barrow studied birds in a Chihuahuan desert and found the abundance and species richness within 21 of 26 species to be reduced and that significant predictors were (generally) being within 1-2km of the nearest road as the length of road increased, distance to the nearest road, distance to the nearest development or a two-way interaction of these variables. It is important to note that landscape factors in conjunction with the road factors were found in many models to be significant (e.g. distance to nearest development, areas covered by different types of vegetation). The traffic density was reported to be between 407-459 vehicles/day with a speed limit of 45 mph. The noise levels were not measured; however, the effect is postulated by the authors to be related to the roads or the associated development.

Noise carries many properties with it including the number, size and speed of vehicles. The noise levels were about 59 dB(A) adjacent to roads and 38 dB(A) in remote areas with a threshold for response of between 27-61 dB(A).

The general conclusion is that some (although not all) bird species are sensitive at least during breeding to noise levels and that the distances over which this effect is seen can be considerable varying from a few metres to more than 3km.

Unlike birds some mammals tend to have more tolerance of road presence and presumably the associated noise. This may depend upon the timidity of the species, nocturnal habits or be due to the lack of need to communicate at the same level as birds.

In country districts badgers, deer and foxes are regularly killed crossing or using the roads. Squirrels and other small mammals also regularly become victims of vehicle collision, however it appears this mainly occurs on roads with relatively low volumes of traffic. Motorway victims mainly occur at night when traffic is lighter. Consequently it could be assumed that in general mammals avoid roads during periods of heavy motorist usage i.e. when noisiest.

In a study of elk movement along interstate 80 in Wyoming (USA) the traffic noise was recorded as an average of 54dB(A) - 62dB(A) for cars and 58dB(A) - 70dB(A) for trucks with little evidence of avoidance up to distances of 300 yards. At the same time there did appear to be a physical barrier imposed by the road. Adams and Geis reported that elk generally avoided roads while deer showed little difference in distribution around interstate highways (monitored at distances up to 400metres from the road).

Road traffic is forever increasing, but air travel is rapidly escalating as well. Some studies have been carried out aimed at reducing strike and kill rates on birds at airports. Most have experimented with noise scaring, which suggests the presence of aircraft noise alone may not deter birds or have a detrimental effect upon them.

Military planes however may have different consequences. A review of the effects of aircraft noise and sonic booms on domestic animals and wildlife was conducted in the USA in 1988 (See Footnote [21]). This report differentiated between both types of noise and commented as follows: -

“Differences in noise from low-altitude subsonic over flight and high-altitude supersonic over flight include the increased duration of noise from a low-altitude over flight, the greater probability that noise from low-altitude over flights will be accompanied by visual perception of the aircraft, and the broad-band frequency distribution of jet engine noise (about 200Hz -20,000 Hz) versus the low-frequency noise of sonic booms (with most of the sound energy between 15Hz -50 Hz).”

The jet engine noise commences in the low frequency band level rising rapidly and steadily to a crescendo passing through the upper limits of defined low frequency noise (400Hz – 900Hz) to peak levels in the higher frequency range at around the upper limit of human hearing (20,000Hz). Whereas the ‘sonic boom’ occurs as both infrasound and low frequency noise, but is contained within a much narrower bandwidth where some of the ‘noise’ is below the threshold of normal human hearing (16Hz - 20Hz).

These levels of frequency are particularly significant as not only are they emitted at a high dB rate (130dB and above) they also occur across bands that fall within the known hearing ranges of most domestic and wild creatures inhabiting both the land and fresh water. Indeed the dB figure given in the above report is 140dB for a jet aircraft taking off at 25metres distance – considerably above the accepted human pain threshold (120dB).

We have already established that animals rely upon hearing to avoid predators, to obtain food and to communicate and thus it has been a determining factor of their evolutionary behaviour. Producing sound does not necessarily mean an animal has a well-developed hearing range. Conversely having ‘good’ hearing does not always go in tandem with vocal ability. A horse for example has a limited vocal range within a bandwidth of 50Hz – 100Hz but can hear sounds across a spectrum of 55Hz – 33,500Hz.

Vocal communication plays an important part in the social interaction of many creatures and the imposition of noise from man-made sources could potentially disrupt the ability of species to communicate or introduce new and possibly disturbing behavioural factors into social groups. (See the squirrel behaviour under the wind turbine section). Tolerance of noise has also to be considered when evaluating the effects upon wildlife.

Aircraft noise (as with other sources) has the potential to mask sounds produced by creatures as they endeavour to communicate thus possibly affecting mating sequences, predator warning or frightening off prey. These are direct affects but secondary impingements could include stress and detrimental changes reducing or eliminating the ability to find water, food and protective cover.

Timing of noise disruption may also play an important part. Night noise might disrupt sleeping patterns. Seasonal noise may disrupt migration thus influencing physical condition resulting in debilitation and have a chain reaction upon other species that are interdependent upon their well-being.

Animals appear to be more sensitive to noise disturbance than humans (Borg, 1981). Possible harmful effects of sound may also relate to the noise content leading to risky actions or as mentioned previously, masking, thus obscuring significant intelligence that otherwise would be gleaned as a safety factor, rather than the actual superimposed sound.

Jet noise and sonic booms are by their very nature often sudden, unexpected and extremely loud. Alarm precipitates nervous reaction, an injection of physiological stress and invariably leads to instinctive flight. Occasionally the reaction is one of combat where the noise source is seen (heard) as a threat to dominance and a creature might consider standing its ground and take up a fighting stance.

Either way stress factors are induced that activates the neural and endocrine systems leading to increased blood pressure and changes in glucose and cortisone levels. Prolonged exposure to severe stress can lead to death. Continuous high-level noise is therefore potentially a severe environmental pollutant.

Sonic booms however are not continuous and should be categorised as occasional sources of disturbance unless the area is a specific military testing ground where frequency would be greater. Generally such noise would be spasmodic and studies (Bell, 1972 and Milligan et al, 1983) indicate that animals are startled by both sonic booms and subsonic low altitude flight. Birds appear to more affected than mammals and sometimes some of the latter adapt to the disturbances. Reactions however are never seemingly predictable but appear similar to those created by other comparable noise sources such as helicopters.

Aircraft noise and sonic booms have been ‘blamed’ for reduction in egg laying by domestic poultry. Tests (unnamed) mentioned in the Manci Report (Footnote [21]) suggest field studies on animals indicate that reproduction of wild populations may be more affected by noise disturbance than domestic populations. The reproductive effects have primarily been the result of disturbance of the animal’s behaviour during the reproductive cycle.

The use of military aircraft at supersonic speeds resulted in some successful claims for damages following alleged injury or loss involving livestock (Ewbank, 1977) and prompted investigation into noise effects on domestic farm animals including the physiological effects of aircraft and non-aircraft noise on dairy cows, goats, pigs and sheep.

Previously a variety of tests recorded differing findings. For example one of the earliest studies of noise effects on cows was an attempt to determine the relationship between the nervous system and the ejection of milk of three Jersey cows at the Kentucky Agricultural Experiment Station (Ely and Peterson 1941).

Nerves were immobilised in the left half of the udder of each cow. After recovering from surgery, all three cows began ejecting milk normally. The desensitised half of the udder was able to eject milk just as well as the intact half. 0ne cow was then subjected to various experiments to determine the effect of the nerve supply to the glands under various conditions, such as fright caused by loud noises.

Fright was induced by exploding paper bags every 10 seconds for 2 minutes just prior to attaching the mechanical milking machine. This resulted in an immediate cessation of milk production. Thirty minutes following exposure to exploding paper bags, 70% normal milk production occurred. No difference in response between the two halves of the udder was observed.

Injections of adrenalin gave similar results. The amount of adrenalin injected appeared to determine the length of time needed before natural milk ejection resumed. Presumably, this length of time would be proportional to degree of fright. Fright, such as that caused by a loud sound, could stimulate the natural production of adrenalin.

Parker and Bayley (1960) studied the effects of jet aircraft noise and flyovers on milk production of dairy herds located near existing air bases. Data for 12 months were compiled on the daily milk deliveries of 182 herds located within 3 miles of eight Air Force bases. Although data were lacking at some bases, results of this survey showed no evidence of effects on milk production resulting from jet over flights or proximity to an air base. Milk yield of dairy cows in an area of frequent sonic booms, Edwards Air Force Base, California, was also similar to the yield of control dairy cows; however, the animals had been previously exposed to at least four to eight sonic booms per day prior to data collection (Casady and Lehmann 1967).

Bond et al. (1974) found no evidence that simulated sonic booms had any effect on eating patterns, total feed intake, or rate of feed intake in dairy cows. However, Kovalcik and Sottnik (1971) found that a noise level of 80 dB (unspecified scale) increased feed intake and the rate of milk-releasing indices, but did not affect the milk yield of dairy cows. (The everyday noise level of the animals' surroundings was 50-60 dB.) Kovalcik and Sottnik (1971) presumed that the noise level of 80 dB was within the limits of the normal tolerance of the animal. When these same animals were exposed to a sudden high-intensity noise (105 dB), feed consumption was reduced as well as milk yield and rate of milk release. The authors found, however, that if the noise is increased gradually, instead of suddenly exposing the animals to the high-intensity noise, the response is not as negative.

Later, Cottereau (1978) stated that simulated sonic booms had no effect on semen quality or quantity of bulls at an artificial insemination centre. Pregnant Charollais cows exposed to 20 simulated sonic booms during the first month of pregnancy gave birth to normal calves. The intensity and frequency of the booms was not described.

Other farm animals however, have shown to be adversely affected. Noise (including jet noise) reduced the milk yield in all five goats used in an experiment (Sugawara et al. 1979). The noise had a greater effect on milk yield within the first 3 months after parturition. Sugawara et al. (1979) suggested that intermittent exposure to noise had a greater effect than continuous exposure. This would seem to be a significant insofar as it may support other suggestions of tolerance to constant noise at certain levels as opposed to sudden noise at varying intervals. (The bird scaring device syndrome).

Pigs exposed to 120dB sound for 6 hours showed an increase of plasma 11-OH-corticosterone and catecholamines (Borg 1981). Exposure to 108dB engine sound for 72 hours resulted in a decreased corticosteroid level, followed by an increase immediately after the stimulation ceased. This biphasic response may indicate a negative feedback effect on the anterior pituitary, which is responsible for releasing ACTH that activates the adrenals during stress. Sound exposure, at least short-term, influences several hormonal systems of pigs.

Excess secretion of hormones from the adrenals, water retention, and sodium retention were observed in castrated male pigs exposed to 93dB (unspecified frequency) continuous noise over several days (Dufour

1980). Excess aldosterone may be induced by stress, resulting in the upset of the electrolyte balance, which can be manifested by hypertension (possibly due to sodium and water retention), excessive urination, and thirst (Dufour 1980).

Only a few studies of the physiological effects of noise on rodents have involved wild animals. A field study by Chesser et al. (1975) involved two populations of house mice near the end of a runway at Memphis International Airport. Adult mice also were collected from a rural field 2.0km from the airport field. Background noise levels at both fields were 80dB-85dB. Noise levels of incoming and outgoing aircraft at the airport field averaged 110dB, with the highest reading reaching 120dB.

Total body weights and adrenal gland weights of mice from the fields were measured. Additional mice were captured from the rural field, placed in the laboratory, and exposed to 1 minute of 105dB recorded jet aircraft noise every 6 minutes to determine if noise was the causative factor. Control mice were not subjected to noise. After 2 weeks, the adrenals were removed and weighed. Adrenal gland weights of male and female mice from the airport field were significantly greater than those of mice from the rural field.

The noise-exposed mice in the laboratory study had significantly greater adrenal gland weights than the control mice. After ruling out stress factors, such as population density, Chesser et al. (1975) concluded that noise was the dominant stressful factor causing the adrenal weight differences between the two feral populations.

A study was conducted on Mitkof Island, Alaska, in 1970 to determine the effects of real and simulated sonic booms on late pregnancy, parturition, early kit mortality, and subsequent growth to weaning of farm-raised mink (Travis et al. 1974).

The study involved 350 yearling and 148 2-year-old females and their progeny (1,845 kits). Treatment animals received either three real sonic booms (averaging 294 $mN/m^2$ overpressure) or three simulated sonic booms (averaging 167 $mN/m^2$) on the day approximately 40% of the females in each group had whelped.

Booms occurred over a 60-minute period; the second boom was 45 minutes after the first, and the third was 15 minutes later. The booms caused transient structural vibrations of $10m/sec^2$ or less on the wooden nest boxes. Mean length of gestation, mean number of kits born alive per female whelping, mean number of kits born alive per female, and mean weights of kits at 49 days of age were similar among treatment groups and the control group.

The observable behavioural reaction of female mink exposed to real or simulated sonic booms was brief and had no apparent long-term effect on the health and well-being of the females and their newborn kits. Most mink returned to pre-boom activities within 2 minutes after each boom and appeared to habituate to the acoustic stimuli and vibration of sonic booms after exposure to only three booms in the span of 1 hour. No panic behaviour, packing of kits, or killing of kits was observed during the boom tests.

During 1973-1974, the Federal Aviation Administration (FAA) studied the effects of sonic booms on the environment during routine U.S. Air Force super-sonic acceptance test flights of F-111 jets southwest of Fort Worth, Texas (Higgins 1974).

The behavioural response of songbirds in an oak wood to F-111 flyovers was noted in one instance. The jets flew over the observation area at 20,000-41,000 ft at Mach 1.0-1.55; peak overpressure values at the site were measured at 0.55-3.25 psf (mean = 1.15).

The continuous songs of birds were completely silenced 4-8 seconds before the arrival of the audible sonic boom. Further study disclosed that this response of songbirds coincided with the arrival of the seismic signal propagated through the ground and preceding the sonic boom shock wave by 4-8 seconds.

This difference in the arrival times of the audible sonic boom and the seismic signal was caused by the greater velocity of the seismic compression wave signal transmitted through the dense earth medium ahead of the audible atmospheric sonic boom shock wave advancing over the Earth's surface at a speed equal to the ground speed of the supersonic aircraft generating the sonic boom.

The observation that songbirds were alerted to the seismic compression waves preceding sonic booms helps explain phenomena described in historical tales and literature regarding a "hush or stillness falling over" an area preceding some remarkable event, such as a volcanic eruption, explosion, or earthquake at sea generating a tidal wave.

When the sonic booms were audible, the songbirds uttered "raucous discordant cries" for a few seconds. Within 10 seconds after the audible boom, the songbirds were singing their "normal songs."

Davis (1967) noted the response of a population of ravens (Corvus corax) to a sonic boom in central Wales. Three or four ravens were idling in the up-currents over a high rock spur between two streams. When the silence was shattered by a "very loud sonic bang as a jet aircraft passed overhead," Davis (1967) heard ravens calling agitatedly and saw small groups flying from all directions and converging over the crest of the spur. In about 5 minutes, 62-70 ravens were present.

They were flapping, soaring, and chasing each other, and often settled briefly on the rocks, with a great deal of noise. Ravens from at least 2 or 3 miles around may have been involved. Within 10 minutes, they started to disperse again, and calling died down considerably. About 30 ravens were still soaring over the hill when Davis (1967) left the area, an hour after the boom.

**Mobile Telephone Masts**

The introduction of mobile technology and in particular the public adoption of cellular telephones has attracted a great deal of media comment. Despite their popularity it seems concern is felt over the prolonged use of the handsets because of radiation emissions close to the brain and the signals conveyed by the transmission equipment attached to masts.

According to the Mobile Operators Association (MOA) radio base stations receive signals from mobile telephones – which are low powered two-way transmitters, and transmit them to other mobile or fixed networks. Commonly called ‘masts’, their antennas can be attached to a freestanding mast or existing structures such as roof tops or water towers.

Base stations have to be placed quite close together otherwise because the signal strength is weak, gaps appear in the ability to receive or make calls. They are also required where customers need coverage. Hence in built up areas the masts are placed about 200m – 500m apart and 2km – 5km apart in rural areas.

There are currently about 47,000 base station sites in the UK, with two thirds of these on existing buildings or structures. With around 62.5million mobile phone subscriptions in the UK and new technology being added all the time, more base stations will have to be built and by 2007 it is possible there will be 50,000.

Many of the base stations use microcells, especially in busy areas and are usually mounted at street level on external walls, lampposts or neon shop signs – often disguised as building features. These microcells have lower radio wave outputs than the larger base stations.

The signals emitted by the ‘masts’ are of a low frequency nature and operate in pulses. A newspaper article[34] reported that health fears about mobile phone masts centred on information claiming signals were transmitted and received on the 400MHz frequency, which pulsated at 17.65Hz. In 2000 the UK Government report on mobile phone safety by Sir William Stewart, a former chief scientific adviser, recommended that frequencies around 16Hz – frequency at which the human brain transmits signals – be avoided as a precaution, even though there was no confirmed health risk.

[34] The Independent: 23.11.2004 “The Mast Crusaders”

There are many operators of mobile technology and masts are shared where practicable. This slightly increases the levels of emissions although different operators might transmit at different power levels, frequencies and at different antenna height and direction. Shared sites are checked and certified for compliance with the international health and safety public exposure guidelines. Emissions are always said to be many times lower than the set ‘safety’ limits.

The cumulative effect might give rise for concern, although operators maintain they ensure compliance with public exposure guidelines. Radio waves decrease rapidly with distance. Approximately each doubling of distance reduces the field by a quarter. Antenna can be within a few metres of each other in the public domain and are said not to raise exposure levels anywhere near the guide limits.

Operators design safety zones around shared antenna sites. They assume worst-case conditions for maximum power levels. Audit of these sites by the Office of Communications (Ofcom) has not so far uncovered any (from around 500 tested) where the levels of emissions exceed the safety levels.

Just as with other sources of low frequency noise or infrasound it has been quite natural for all reports and information to focus upon the effects upon humans. Questions do arise however insofar as impact on other creatures is concerned. For example, as shown above pains are taken to ensure the majority of transmission masts are placed above street level, not only for better reception but also to ensure the emissions are not constantly affecting the public. Birds however frequent the masts and spend a lot of time nesting, perching, roosting and flying at heights that must directly correspond with the beams of emissions.

The house sparrow is in decline within some city areas, particularly London where it has disappeared entirely from some previously common haunts. This bird has been shown to have an absolute sensitivity to sound pressure level at –8.31dB SPL and detect low frequency sound of 0.29kHz.[35] Elsewhere in this report it has been stated that birds generally hear best at frequencies between about 1hZ and 5hZ.
Could the ‘unheard’ frequency at which the emissions from masts are transmitted and received be detected by the sparrows and cause them sufficient distress or alarm to abandon their habitat? Perhaps it is not a coincidence that this species is thriving in many rural areas where mobile phone masts are further apart and less numerous.

Studies are ongoing into the decline of the sparrow and a number of suggested reasons have been advanced for the reduction in numbers including, lack of food, particularly aphids, which are fed to nestlings, possibly through the use of unleaded petrol, cat and Sparrow hawk predation, reduced nest sites and cleaner streets thus less foraging opportunities. None of the published reports have mentioned low frequency sound.

One report by DEFRA[36] highlights the decline of the sparrow since the end of the 1970’s with the main fall in the South East but with increases in Scotland and Wales. The greatest declines have been since the 1980’s in suburban and urban gardens. Rural gardens being the most favoured habitat now. These facts coincide with the increase in technology producing low frequency noise and infrasound in built up areas, particularly from mobile phone masts. Clearly an investigation is needed, if only to dispel this suggestion as incorrect.

The DEFRA report states high nest failure rates have been recorded in the areas where population of sparrows is declining most rapidly, namely South East England. It is reasonable to surmise this is where the greatest proliferation of mobile phone antenna is based.

**High Voltage Cables (Power Lines)**

The National Institute of Environmental Health Services and National Institute of Health (Australia), 2002 completed a detailed explanation of the effects of power line radiation but did not mention anything about ‘noise’. Electromagnetic transmissions however, are emitted at 50Hz or 60Hz and are audible. Sometimes a ‘fizzing’ effect is heard.

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35 Avian Hearing and the Avoidance of Wind Turbines: R Dooling Ph.D June 2002
36 DEFRA Status and population trends of the House Sparrow and Starling 2002

In general it seems the 'waves' produced by power carrying cables (either above or below ground) would need to fluctuate to provide a stimulus before being 'detected' by the human brain. Presumably this would also apply to other creatures.

Most sound waves from power lines are believed to be steady in nature and do not rise and fall sufficiently for the human brain to detect the changes as audible noise. Likewise any thermal effect from the electromagnetic energy produced is absorbed by body tissue, including the head and ear and would probably, occur at very high frequencies (200MHz – 10,000MHz).

**<u>Miscellaneous Sources</u>**
Studies involving a miscellany of noises are reproduced below and were taken from the report by Karen M Manci et al featured previously in these notes (See Footnote [21]).

The initial physiological responses to sound measured in sheep were heart rate and respiratory rate (Ames and Arehart 1972). Early-weaned lambs were exposed to three sound types:

(1) United States of America Standard Institute white noise
(2) Instrumental music
(3) Intermittent miscellaneous sound (IMS).

Each sound type was studied at two sound pressure levels, 75dB and 100dB. The IMS consisted of the following sounds: electrical and diesel engines, jet and propeller aircraft, roller coasters, stadium noise, fog horns, firecrackers, machine guns, cannons, rain, and band marches. White noise and music exposures were continuous. The control period was 21 days with a background noise level of 45 dB. Initial exposure to 75dB and 100dB white noise did not cause a change in heart rate in acclimated lambs. In non-acclimated lambs, initial exposure to 100dB white noise significantly increased heart rate. During the entire test period, non-acclimated lambs exposed to 100dB white noise had significantly higher heart rate than lambs acclimated at either 75dB or 100 dB.

Respiration rate for acclimated lambs was constant when initially exposed to 75dB, increased rapidly during the first hour, and peaked during the eighth hour. Non-acclimated lambs showed little change in respiration rate until the fourth hour, when a rapid increase occurred. After 8 hours of exposure to 100dB, both acclimated and non-acclimated lambs had significantly higher respiration rates than controls and lambs exposed to 75dB. This trend continued for the 12-day test period. Initial exposure to music at 75dB increased the heart rate. Acclimated lambs exposed to 100dB music had significantly higher heart rate over the 12-day period compared to lambs exposed to 75dB. Non-acclimated lambs had significantly higher heart rate than acclimated lambs subjected to both 75dB and100 dB. Non-acclimated lambs exposed to 100dB IMS had significantly higher heart rates than acclimated lambs; however, respiration rates were highest at 75dB.

Data presented in Ames and Arehart's (1972) study indicated that some physiological responses to sound were characteristic of those of the stress response (e.g., adrenally oriented responses and acclimation to the sound environment). A sudden change that startled an animal usually resulted in tachycardia through action of catecholamines, or bradycardia caused by vagal stimulation. Sound exposures also usually resulted in vagal stimulation, except for non-acclimated lambs exposed to 100dB white noise. Heart rate response varied less when exposed to music, which suggests that music is less stressful than other sound types. Responses apparently varied by sound pressure level and duration. Respiratory rate appeared to be dependent on sound type (continuous rise in rate during IMS exposure) rather than sound level, with a possible effect of intermittent play versus continuous exposure.

Arehart and Ames (1972) also determined the effect of sound types and intensities on growth and feeding efficiency on early-weaned lambs. Sixty lambs were exposed to the same three sound types and intensities (75dB and 100dB) of the above experiment. White noise at 75dB significantly increased the average daily weight gain and feeding efficiency. Acclimated and non-acclimated lambs subjected to 100dB white noise had significantly lower feeding efficiency, which was still higher than the feeding efficiency during the control period. Music at either intensity had no significant effect on performance. Lambs subjected to IMS noise consumed less feed per day than lambs exposed to 75dB white noise or music. Average daily gain in weight was significantly higher at 75dB compared to controls and 100dB IMS exposure.

The pooled data from Arehart and Ames's (1972) experiments indicated that intensity of sound significantly affected growth rate in early-weaned lambs. Again, music was less stressful than other sound types. The data also suggested that acclimation to sound occurred, with respect to daily growth rate. All non-acclimated lambs exposed to 100dB noise gained significantly less weight than lambs previously exposed to 75dB noise, suggesting that long-term study is needed to determine whether detrimental effects would actually occur during long-term feeding trials.

Harbers et al. (1975) studied the digestive response of yearling wethers to the same sound types and intensities used in the two studies above: white noise and music presented continuously and IMS. In control metabolism trials, sheep were placed in metabolism crates and exposed to 45dB background noise for 14 days. Dry matter feed intake was less when sheep were exposed to 75dB or 100dB of each sound type compared to controls. Type of sound had no effect on feed intake. Water intake and urinary output appeared to depend on sound type and not intensity. Sheep exposed to IMS consistently drank more water and excreted more urine than sheep exposed to continuous sounds, white noise, or music. If intermittent sounds are more annoying than continuous noise, this might explain why these lambs drank more water. Sound level, type, and the interaction of these influenced faecal moisture. Lambs exposed to 100dB music or IMS had less faecal water. Music at 75dB resulted in more faecal water excreted in those lambs, and less when exposed to 75dB white noise and IMS. However, faecal water was not related to water intake.

Exposure to IMS at 75dB and 100dB not only increased water intake, but also increased metabolizable energy of the ration and improved the apparent nutrient digestibility. Sound intensity did not affect apparent digestibility coefficients. The high digestibility coefficients for lambs exposed to intermittent sounds suggests that those types of auditory stimuli influenced the digestive system. This increased digestibility of feed, along with water retention, may partly explain the improved growth gain in lambs exposed to IMS. IMS increased metabolizable energy by 100 Kcal/day; no effect of intensity was observed.

Sheep probably acclimated to continuous and intermittent sound of 100dB or less. None of the sound stimuli seemed to adversely affect digestibility, with intermittent sound actually stimulating digestion. All of the above mentioned effects were short-term only. The effect of intermittent sound on long-term feed intake and digestibility should be investigated. The increased metabolic rate, had it continued, may have proved detrimental to the animal by shortening its life span or causing other physiological changes. Noise exposure above background level may play an important role in digestive efficiency, metabolic balance, and growth rate.

**Thunder**

Ogle and Lockett (1966) examined the effects on rats of recorded thunderclaps of 3 to 4sec duration, frequency range of 50Hz to 200Hz at 98dB to 100dB SPL, presented for 2 minutes out of every 15 minutes for 45 minutes. This was compared with effects from a pure tone of 150Hz at 100dB presented in the same sequence of time.

Urine was collected for analysis of sodium and potassium. Responses were compared among animals that were intact, that had denervated kidneys, and that had neurohypophyseal lesions. Thunderclaps increased the urinary excretion of sodium and potassium by intact rats but not by neurohypophysectomized rats.

Ogle and Lockett (1966) concluded that the thunderclaps produced emotional responses, and the pure tone did not. Thunderclaps affected the hypothalamus, resulting in excretion of oxytocin and vasopressin, which produced increases in sodium and potassium excretion with no increase in urine flow.

**Other atmospheric and natural sources**
The Krakatoa volcano erupted in 1883 intriguing scientists and others because of the sub audible sound waves they experienced thousands of kilometres away.

Modern equipment in the form of microbarometers can detect this type of infrasonic pressure movement and are also used to monitor nuclear test explosions and military type rocket firing.

In addition natural phenomena including earthquakes, tornadoes, landslides, aurora and meteors plus simple turbulence produce levels of infrasound that can be detected by sensitive recording instruments.

Driven by the cold war and commencement of nuclear test bans the need for monitoring increased to levels that required a network of sensors to be set up to probe the surface of the earth and the oceans as well as check for atmospheric movement.

This comprehensive coverage should produce information from listening posts that will help understand far more than manmade explosions. All unusual instances of infrasound should feature in the results and may even aid prediction of certain events or at least provide early warning of disasters such as a tsunami.

In some ways it seems we are playing catch-up with birds and animals as they often give early warning of disastrous natural events beforehand, albeit with only short notice. Unfortunately, unlike the old time miners utilising a canary to detect gas it is improbable that we will be able to harness this ability to good effect.

**Chain saws and logging trucks**
A study into road noise in America commented upon different sources of sound and the effects upon a variety of species including raptors. In one instance when referring to aircraft noise the report stated, "Chain saws were found to be more disturbing, although the average sound level was only 46dB(A). Grubb et al. reported that there was no discernable effect of logging trucks on breeding goshawk (*Accipter gentiles*) female or juvenile at a distance of 500metres. Noise levels were sporadic with peaks at 50dB(A) at a frequency of about 80Hz."

**Plant and Appliances**
A health study surveying human epidemiological effects[37]due to noise exposure in or near domestic buildings revealed a considerable number of factors with adverse effects from low frequency noise.

Noise measurements from plant and appliances were recorded and comparisons made between two groups of people. A test group was exposed to sound that included low frequency noise and the control group was exposed to a similar level of A-weighted sound level but had no LFN content.

There were quite substantial differences displayed in the levels of anxiety and other symptoms of distress between the groups after the exposure period. The test group suffered more annoyance, sleep disturbance and pain than the control group.

The dB levels were not particularly high but the adverse effects were significant as shown in the following tables:

**Noise Exposure Table**

| Noise Source | $L_A$dB | Percentage of people exposed | Kind of exposure |
|---|---|---|---|
| Fans | 26 – 31 | 33 | Day, intermittent |
| Central Heating Pumps | 23 – 33 | 18 | Night, day intermittent |
| Transformers | 20 – 23 | 30 | Continuous |
| Refrigeration Units | 21 – 32 | 19 | Night, day intermittent |

[37] Mirowska and Mroz, 2000

**Symptoms Table**

| Symptom | **Test Group %** | **Control Group %** |
|---|---|---|
| Chronic fatigue | 59 | 38 |
| Heart ailments anxiety, stitch, beating palpitation | 81 | 54 |
| Chronic insomnia | 41 | 9 |
| Repeated headaches | 89 | 59 |
| Repeated ear pulsation, pains in neck, backache | 70 | 40 |
| Frequent ear vibration, eye ball and other pressure | 55 | 5 |
| Shortness of breath, shallow breathing, chest trembling | 58 | 10 |
| Frequent irritation, nervousness, anxiety | 93 | 59 |
| Frustration, depression, indecision | 85 | 19 |
| Depression | 30 | 5 |

The marked increases in insomnia, shortage of breath and indecision, if repeated in animals exposed to similar levels of LFN might prove fatal. Lack of sleep would affect awareness, create lethargy and coupled with indecision be likely to hinder the ability of an animal to escape a predator.

This study appears to confirm the work of others investigating the effects of low frequency noise upon human behaviour (Persson-Waye et al., 1997. Persson-Waye and Rylander, 2001) where the findings in each case revealed the test subjects were not as happy, suffered reduced orientation, annoyance and disturbed concentration in comparison to the control groups.

Persson also found in earlier works (Persson et al., 1985. Persson and Bjorkman, 1988) that by comparing A-weighted noise levels the annoyance from the low frequency noise was greater than from higher frequency noise at the same A-weighted level and utilising dBA as a measuring scale underestimates annoyance for frequencies below about 200Hz.

Annoyance to humans would most likely manifest as disturbance insofar as wildlife is concerned thus stimulating the ‘flight or fight’ instincts. This could lead to bird nest abandonment, animals breaking cover or shelter and panic or aggressive behaviour amongst aquatic species that could not escape their environment.

The use of ‘A’ weighting is now considered inadequate for low frequency and infrasound noise assessment. ‘C’ weighting and ‘G’ weighting respectively should be used. (See: A Review of Published Research on Low frequency Noise and its Effects, May 2003 by Dr Geoff Leventhall et al).

**The National Noise Incidence Study 200/2001 (United Kingdom)**

This resulted in a report running to three volumes being published following a study of noise exposure based on 24-hour measurements outside a sample of 1160 dwellings in both urban and rural areas..

The findings denoted that allowing for 3% leeway either higher or lower, 54% of the population of the UK live in dwellings exposed to day-time noise levels above the World Health Organisation (WHO) recommended levels of 55dB $L_{Aeq.day}$. Similarly 67% (plus or minus 3%) of the population live in dwellings exposed to night-time noise levels above the WHO level of 45dB $L_{Aeq.night.}$

Noise was placed ninth in a list of twelve environmental problems with 84% of respondents reporting hearing noise from traffic and 71% noise from aircraft. 40% were bothered, annoyed or disturbed to some extent by road traffic noise.

The measurements were taken at 1.2m above ground and 2m away from the outside walls. As the majority of the noise seemingly originated from road traffic and aircraft it seems much of the content would include LFN and infrasound. The figures emphasise the astonishing extent to which noise is ever present and must surely be problematical to wildlife.

**DISTRESS CAUSED BY DISTURBANCE TO WILDLIFE AND DOMESTIC ANIMALS**
**(Including infrasound and low frequency noise)**

An Internet publication (Wildlands CPR) contains a synopsis of a lengthy paper written and submitted by D. J. Schubert as a petition against Off Road Vehicle use in U.S. National Forests. Extracts have been included in the following amalgam of comment upon animal suffering from human induced noise and general disturbance factors.

Distress (stress) is a consequence of disturbance, which can, if prolonged, cause substantial adverse impacts upon individual animals. Stress may be caused by both physical and psychological factors, but in either case results in physiological changes to the animals.

Exposure may be short or long term leading to acute or chronic symptoms. Hence a loud and unexpected noise may cause a bird to abandon a nest and/or young or persistent noise might drive an animal from a frequented habitat.

Off Road Vehicle (ORV) use for example, may cause both physical and psychological stress to a wide range of animals as a result of noise, pollution, activity patterns, and direct and indirect harassment or disturbance. The effects of recreation-induced stress, including lower reproductive output (Geist 1978), may not be evident immediately, but may appear days to years after disturbances (Gutzwiller 1991). Moreover, recreation-induced stress exacerbates the effects of disease and competition, leading to higher mortality well after disturbances occur (Gutzwiller 1991).

Birds are particularly prone to noise disturbance. Whilst not specifically commenting upon LFN or infrasound there is no reason to suppose the results from the following study résumés would be any different if the disturbance source included or resulted entirely from such causes.

In birds of prey, nesting failures (Boeker and Ray 1971), lowered nesting success (Wiley 1975, White and Thurow 1985), displacement (Andersen et al. 1986), and changes in wintering distribution and behaviour (Stalmaster and Newman 1978) were documented in response to human disturbance.

In their study of home-range changes in raptors exposed to increased human activity levels, Andersen et al. (1990) documented that increased military use in a site previously subject to low human use resulted in a shift in home range and activity areas for several raptorial species including red-tailed hawks, golden eagles, ferruginous hawks, and Swainson's hawks.

Additionally, the raptors increased the size of the area used and increased movements outside of the previously used areas, except during military use activities when several birds remained in isolated areas within their home ranges. Two birds, a ferruginous hawk and a Swainson's hawk completely abandoned the area not returning until the following spring.

Besides the obvious impacts of habitat abandonment, the changes in home range size, activity areas, and use of habitats; increased human disturbance may adversely impact upon an individual bird's energy budget, and productivity might decrease with subsequent impacts at the population level. If different raptor species demonstrate different levels of tolerance of human activities, in time continued human disturbance could result in a shift in the species composition in the area in favour of the more tolerant species (Voous 1977, Craighead and Mindell 1981, Andersen et al. 1990).

The physiological impact of stress on animals has been the subject of many studies, which have somewhat conflicting results. Selye (1950) suggested that an exhaustion of the adrenal cortex occurs during prolonged stress exposure while others concluded that prolonged exposure to acute stress results in a decline in adrenal sensitivity (McNutty and Thurley 1973, Ader 1975).

Alternatively, Sapolsky (1983) suggested that chronic stress might cause a decline in cortisol production as a result of impairment of pituitary ACTH production, while others (Friend et al. 1977, 1979, Paul et al.

1971, Barrett and Stockham 1963) provide data, which demonstrates that stress tends to increase adrenal sensitivity to an acute stressor.

If chronic exposure to stressors causes sustained elevated glucocorticosteroid levels, impairment of immuno-defensive mechanisms in affected animals may occur making the animals more susceptible to disease (Jensen and Rasmussen 1970, Paape et al. 1973, Hartman et al. 1976, Stein et al. 1976).

Some animal studies have concentrated on the results of deliberate exposure to disturbance. Harlow et al. (1987) using domestic farm sheep determined that mild, medium, and severe stress events resulted in heart rate and plasma cortisol changes. Heart rate during mild stress events returned to resting values by 10 minutes post-stress event, while medium and severe stress events resulted in elevated heart rates for 20 and 60 minutes post stress event, respectively.

Plasma cortisol levels were significantly elevated above resting values within minutes post-stress, with cortisol levels returning to pre-stress levels 30 minutes after removal of the mild stressor; as compared to continuously elevated cortisol levels from 90 to 180 minutes for both the medium and severe stressors.

During chronic stress events, cortisol levels in the sheep were significantly elevated from day 5 through day 24 at which time the random noise generator used to create the stress event failed. Once the generator was repaired and restarted, cortisol levels increased to previous chronic stress values.

The results of Harlow et al. (1987) do not support the concept of adrenal exhaustion or hypersensitization nor suggest that habituation to stressors occurred, perhaps because of the irregular, unpredictable interval of the noise stimuli.

As indicated by Harlow et al. (1987), chronically elevated blood cortisol may adversely impact the efficiency of animal production by reducing weight gain and otherwise affecting animals in captivity (Van Mourik and Stelmasiak 1984, Van Mourik et al. 1985) and decreasing antibody production, thereby inhibiting or suppressing the body's ability to resist disease (Roth 1984, Jensen and Rasmussen 1970, Huber and Douglas 1971, Revillard 1971, Paape et al.1973, Hartman et al. 1976, Stein et al. 1976).

These impacts, particularly if chronic, can result in: increased sickness, disease, and death; a decrease in animal productivity (Knight and Cole 1991, Anderson and Keith 1980); and ultimately result in population declines (Anderson and Keith 1980).

Harassment of mule deer by all-terrain vehicles, for example, resulted in reduced reproduction the following year (Yarmaloy et al. 1988). Common loons experienced reduced productivity with increased human contacts (Titus and VanDruff 1981).

The previous paragraphs clearly denote that stress is a cause for concern with regard to the effects upon creature behaviour. Noise even when at levels below normal receptive hearing is a cause of distress.

Noise can be perceived as a threat and Ising and Ising studied this reactor in 2002. They found a body releases cortisol even during sleep if noise is deemed threatening. Stress disrupts the normal cortisol pattern. Children were studied after being exposed to changed traffic levels involving exposure to high levels of nighttime lorry noise. Indications were that the LFN content produced concentration problems in the children.

Laboratory studies have also been conducted upon human subjects that confirm enhanced salivary cortisol levels were produced by exposure to low frequency noise (Persson-Waye et al., 2002). A further study (Persson-Waye et al., 2003) found that levels of the cortisol awakening response were depressed after exposure to LFN and was associated with tiredness and negativity through the effects of LFN upon sleep quality.

These experiments upon humans all confirm that stress and disturbance are interrelated. There is no reason to conclude the effects upon wildlife would differ.

A recent investigation and report published by the UK Noise Association[38] into wind farms and noise concluded that the symptoms people 'feel' from LFN emitted by land based wind turbines are very similar to those associated with vibroacoustic disease.

This publication contained a number of examples where human distress was reported apparently resulting from low frequency noise and or infrasound affecting them and their homes.  Complaints included headaches, worry, lack of sleep, anxiety, irritation and reports of 'feeling' as much as 'hearing' the noise.

One of the recommendations made by the report is that no wind turbines should be sited closer than one mile away from the nearest dwellings and there may even be occasions where a mile is insufficient.

Bearing in mind that many other creatures may be 'trapped' in habitat within these distances there would also seem to be potential for stress and harm to them as well.

Another study for the Ministry of Defence by Keele University concluded seismic signals from wind turbines registering up to 7.5hz could be detected ten miles from a wind farm.  Presumably however the dB level at that distance would be low, but it demonstrates how widespread LFN can become from a known manmade source.

Rural areas are usually much quieter than urban conurbations and the sudden introduction of greater noise levels by building a new arterial road; airport or even a wind farm is bound to have an immediate effect upon the residents of sparsely populated regions.

What is almost invariably forgotten during such eventualities is that the resident population includes the natural inhabitants as well as humans.  Whereas the human population tends to endure the noise, albeit under sufferance the wildlife (creatures in still freshwater excepted) is far more likely to be driven away, especially if they experience symptoms similar to those found stressful by their human counterparts.

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[38] Location,Location,Location : John Stewart July 2006

## HABITUATION

Although people often believe they get used to night time noise, physiological tests point to the contrary. Studies have shown that while the subjective response improves with time, cardiovascular responses remain unchanged (Muzet, 1983). Vallet et al. (1990) conclude that habituation is not complete, even after 5 years of exposure to noise.

There is no reason to suppose the effect upon other mammals, birds or aquatic species would be any different, especially those with nervous systems similar to man.

Impulsive or other sudden loud sounds can produce a startle response that does not completely habituate with repeated, predictable exposures (May and Rice, 1971).

Knipschild and Oudshoom (1977) avoided some of the pitfalls characteristic of epidemiological studies by examining a population near the Amsterdam airport before and after an increase in exposure to aircraft noise, and comparing it to a non-exposed nearby population.

The dependent variable was the purchase of certain prescription drugs: tranquillisers, sleeping pills, antacids, and cardiovascular drugs. The investigators found that the use of these drugs in the non-noise area was essentially stable, whereas the use of most types of these drugs in the area newly impacted by noise increased steadily over the years investigated. This increase was especially noticeable for anti-hypertensive drugs.

The evidence is fairly clear that so long as the stimulus remains the same, noise annoyance does not subside over time (e.g., Fields, 1990). Griffiths (1983) cites studies showing no habituation for highway noise from four months to two years after the opening of new routes. De long (1990) found that annoyance in a previously surveyed community increased by 10 percent with no change in noise levels. He suggests that this increase could represent a shift of internal criteria due to increased publicity and other factors, or perhaps an increase in physiological sensitisation.

Annoyance is not peculiar to human beings, it is just easier to grasp as a human concept as the type or degree can be communicated in ways we more readily understand. Unfortunately we cannot simply ask for example, a frog, if the noise from water pumps gets on its nerves. We have to rely upon behavioural study and assume if the frog leaves the vicinity it might have been due to the noise emitted by the pumps and then eradicate all other known causes and possibilities.

It has already been noted elsewhere in this literary report that bees did not habituate to noise and actually ceased movement for an appreciable time after exposure. Conversely comment has also been made that mink appeared to become used to acoustic stimuli and vibration and the bird-scaring device that emits a regular sound is not as effective as the intermittent unpredictable noise.

Accordingly it appears the type of noise, frequency (in terms of period scale or regularity as well as the actual Hz level), unexpectedness and ‘loudness’ may play a part in habituation as much as the nature of the species themselves. Yet such apparent habituation may simply be that certain species are more tolerant than others to certain levels of disturbance.

Starlings for example have been observed reacting to the explosive sound of a bird-scaring machine[39] by flying en masse from a temporary roost and then returning to settle again in the same area after a few minutes. Possibly the urge to feed overwhelms the ‘fright’ once it is interpreted as temporary and no other obvious source of danger arises.

[39] Noted by the author on various occasions during 2005 and 2006.

The 'silent' noise of infrasound and LFN at the lowest end of the spectrum being emitted continuously would appear to be more troublesome than an occasional loud retort. Inaudibility other than in a tactile sense could create long-term distress if the affected creatures could not escape exposure and habituation would be unlikely to occur.

Audible low frequency traffic noise can produce a partial habituation and has been mentioned as leading to possible familiarity causing danger indirectly, such as a creature being 'used' to the sound and taking a risk to cross a road.

Birds and other wild creatures can be tamed with the repeated provision of a food supply. They would still be startled by intervention of an unexpected noise but also seem to overcome fear of some types of noise as evidenced by flocks of gulls following a tractor and plough. This is not true habituation but is more likely a calculated assessment of the situation where the abundance of food is balanced against the likely-hood of intervening danger.

On the other hand familiarity and tolerance sometimes appear to grow in tandem. Rabbits whilst extremely nervous of any unexpected movement will quite happily feed alongside of a noisy and busy road provided there is sufficient distance between them and the regular passing traffic. Youngsters to their cost often have complete disregard for the danger and seem oblivious to the traffic sounds.

Habituation is therefore possible in certain circumstances but might still result in creature damage or distress occurring. There would also appear to be degrees of habituation or tolerance, which may or may not be harmful.

In general it seems that habituation cannot be relied upon as a creature safeguard against the emission of either continuous or spasmodic LFN and infrasound.

See Appendix B for a summary of the effects of noise upon creatures.

**CONCLUSION AND RECOMMENDATIONS**

Behavioural studies of the effects of low frequency noise and infrasound upon wildlife are few and far between. Those that have been conducted seem conclusive in their findings in that all confirm harm is possible to living creatures when exposed to prolonged high intensity noise levels.

Mostly it appears noise is just as stressful to wildlife as to humans whether of low or high frequency but is species dependent with regard to the extent of the effects. Generally, creature response is one of appearing startled if the noise is sudden with increased stress if prolonged. In essence, as might be expected, the effects are similar to human behaviour.

The absence of controlled experiments is understandable for rarely is it possible outside of laboratory conditions to create situations that replicate 'the real thing' and to project the findings from an artificial environment could lead to questionable results.

Naturally occurring wildlife populations are undoubtedly sensitive to environmental noise imposed upon them by manmade features. Indeed the level of sensitivity is largely determined by their response to transient perturbations (Shepherd and Horwood 1979). When the source of noise is spasmodic or infrequent a return to normal might be anticipated and recovery rate maybe comparatively quick.

Whilst this suggests occasional disturbance is seemingly harmless or relatively innocuous it does depend upon the duration between events as well as other factors. Regular pulses of sound that occur between long intervals without disturbance can sometimes lead to habituation, but on other occasions create just as much of a startle factor as the 'one off' event.

Thus at times the startle factor seems to be of little consequence although there are exceptions such as abandonment of habitat or in the case of nesting birds, desertion of eggs or young. More prolonged and intense exposure however, has a worsening effect and in the case of species contained within an enclosed environment, such as pond dwelling creatures the results could be significantly harmful.

Despite an undoubted increase in general noise levels and the growth of manmade inventions producing differing levels of sound, very little progress seems to have been made in terms of actual research into the effects upon wildlife over the past 30 years.

Environmental impact assessments rarely consider noise effects on wildlife. According to Bender in 1977 a complete and accurate assessment of a given impact should include an assessment of how animals will react (both physically and behaviourally) to various noise levels of varying frequencies produced by the impact.

In 1980 Fletcher stated that further research is needed to answer critical questions about the effects of noise on animals, including long and short term noise effects and the effect of noise on declining animal population regardless of the cause of the population decline.

By 1988 Manci et al. still reported a lack of field studies and opined the vital link missing in understanding the effects of noise on wildlife was information concerning observation of behavioural response to the physiological changes brought about by noise exposure.

Despite the opportunities offered by proliferation of wind turbines, both on and off shore during the late 20$^{th}$ C little or nothing of substance has materialised regarding the influence of LFN and infrasound on wildlife behaviour or their habitat except an underlying cause for concern.

Quite clearly further research is required in an endeavour to resolve critical aspects concerning the effects of noise on land based animals and fresh water creatures. These should embrace studies of affected species both as individual creatures and in accumulated groups (e.g., shoals) to examine the acoustic frequency, intensity and temporal patterns of significant sound sources upon mating, habitat, alarm response and nurturing.

In addition investigation of the spectrum of environmental sound upon wildlife hearing sensitivity and effects of noise on declining populations of wild creatures should be undertaken. Attention should also be paid to examining the direct stress effects of noise combined with any other related factors e g., habitat damage on wildlife behaviour covering both long and short-term exposure periods.

Prediction of the consequences of low frequency noise and infrasound upon wildlife is difficult to second guess for in addition to not being broadly species dependent it is also not entirely habitat relative. Some creatures could adapt and some could not. Some habitats attenuate sound others intensify it.

In an ideal world a full safety first approach would be adopted and low frequency noise or infrasound emissions would be prevented from affecting wildlife entirely. Unfortunately the doctrine of impossible perfection cannot be applied. Consequently further studies should be made of existing and known localities 'suffering' exposure to this type of noise.

Representations must be made wherever and whenever possible to those responsible for planning, constructing, building, erecting and utilising equipment that emit low frequency noise and infrasound to adopt a proactive and protective attitude towards wildlife.

The track record is neither admirable nor encouraging despite tightening of wildlife legislation across Europe. Even the sudden shift of high-level emphasis upon combating global environmental change resulting from apparent human climatic influence does not auger well.

Permitting construction of vast numbers of large-scale renewable energy projects that produce virtually continuous emissions of infrasound could have wide-spread, marked adverse consequences for the creatures they are intended to help protect.

More factories will be built to provide the equipment used to harness wind, water and solar power as well as additional nuclear power stations. Old power stations will be rebuilt or demolished. All will give rise to some levels of low frequency noise during the construction process and more large transport vehicles will be required to move equipment and spoil from excavations.

Meanwhile there is unlikely to be a reduction in road, rail and air travel or erection of new housing, schools, shops and offices in areas currently inhabited by wildlife. This means more quarrying, road laying, rail improvements, airports and building activities encompassing green field sites.

The prospects are not good. Infrasound and low frequency noise problems will multiply unless more stringent checks are devised at the manufacturing and operating stages. This can only be done by stricter legislative controls on noise emissions and more sensitive placement of any structure that has the capability of emitting these types of sounds.

Measuring methods must therefore be reviewed to include 'C' Weighting and 'G' Weighting at all stages of planned development where LFN and infrasound emissions are anticipated.

Planning authorities should be properly equipped with the means, personnel and equipment to undertake noise investigation and monitoring for at present it appears in many instances they are not able to embark upon even the most rudimentary testing.

An independent environmental assessment is essential to include infrasound and low frequency noise tests at source with prediction models showing the anticipated noise levels at progressive distances and showing the predicted spread.

The assessment must also make a complete study of all wildlife in and immediately beyond the projected vicinity with a proper chronicle of species over a realistic period commencing with an intensive base line study of one year of full and representative observation before a planning application is submitted.

Current wildlife bodies such as the various charities and trusts concerned for wildlife and habitats could carry much of this work out if appropriate government funding was diverted and controlled for the purpose.

Thereafter regular, periodic seasonal monitoring should be enforced as part of the planning acceptance, conditional upon immediate cessation of noise emission if found detrimental to any affected species.

Unless the problem is recognised as real and acute the potential for further chronic and significant harm to land based animals and fresh water creatures will multiply and almost certainly contribute to the progressive decline in species and habitat.

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**APPENDIX A**


i) "Selected Health risks caused by long term, whole body vibration" by Seidel H. Federal Inst. Of Occupational Health, Berlin. (Am J. Med. 1993 Apr. 23(4) ; 589 – 604.)

ii) "Characterising the effects of airborne vibration on human body vibration response" by Smith S.D. Air Force Research Lab., Wright – Patterson AFB, USA. (Aviation. Space Environment. Med. 2002 Jan; 73 (1); 36 – 45

iii) "Low frequency noise enhances cortisol among noise sensitive subjects during work performance" by Kerstin person-Waye. J Bengtsson, R. Rylander, F. Hucklebridge. P. Evans, A. Clow. (Dept. Environ. Medicine, Univ. of Gothenburg. (Life Science 2002 Jan 4; 70(7) 745 – 58. .

[See also by same team "Effects of night time LFN on the cortisol response to awakening and subjective sleep quality)

iv) "Noise induced Endocrine Effects & Cardiovasccular Risks" by H. Ising, W Babisch, B. Kruppa, Federal Environ. Agency, Inst. Of Water, Soil & Air Hygiene, Berlin.(Noise Health 1999; 1 (4); 37 – 48.

v) "Coping with stress; Neuroendocrine Reactions & Implications for Health" by U. Lundberg, Dept. of Psycchology, Stockholm. (Noise Health 1999; 1 (4); 67 – 74

vi) "Possible health effects of noise induced cortisol increase" by M. Spreng. Dept. Physiology, Univ. Erlangen, Germany (Noise Health 2000; 2(7); 59 – 64

vii) "Acute and chronic endocrine effects of noise": Review of the research conducted at the Inst. For Water, Soil & Air Hygiene, Berlin. H. Ising, C. Braun (Noise Health 2000;2(7) 7 – 24.

**APPENDIX B**

**Creatures and the effects of noise exposure**

| Species | Effects |
|---|---|
| Alligators | Use infrasound for communication |
| Amphibians | Displacement by traffic noise |
| Badgers | Avoid traffic at noisiest periods |
| Bees – Honey | Ceased moving up to 20 minutes and didn't habituate |
| Bird – Black Tailed Godwit | Traffic noise reduced density and breeding numbers |
| Bird – House Sparrow | LFN from mobile phone masts – possible contributor to decline |
| Bird – Lapwing | Traffic noise reduced density and breeding numbers |
| Bird – Oystercatcher | Traffic noise reduced density and breeding numbers |
| Bird – Raptors | Disturbed by chain saws |
| Bird – Raven | Distress and disturbance from sonic booms |
| Bird – Skylark | Traffic noise reduced density and breeding numbers |
| Bird – Stone Curlew | Traffic noise, movement caused disturbance |
| Bird – Waterfowl | Traffic noise reduced density and breeding numbers |
| Bird – Willow Warbler | Lower density of territorial males due to traffic noise |
| Birds | 17 of 23 species negatively affected by road noise |
| Birds | Masking effect of LFN exposed to wind turbine rotor blade danger |
| Birds | Communication (song and calls) masked by LFN |
| Birds | Silenced by anticipating seismic signal preceding sonic boom |
| Cattle – Dairy | Reduced haemoglobin and increased glucose in blood by LFN exposure from tractor |
| Chinchilla | Auditory damage |
| Cod | Affected by Wind Turbine Noise at 120dB at 16Hz |
| Cow | Fright noise led to 30 minute cessation of milk production and reduced feed intake |
| Deer | Displacement by traffic noise |
| Dog – Poodle | Heard extremely soft infrasound tone (-4dB) |
| Dolphins – Bottle Nosed | Possible interference with vocal range |
| Earthworms | Move towards surface at 5Hz |
| Elephants | Use infrasound for communication |
| Elk | Avoidance of road noise |
| Fish | Negative response and avoided acoustic field |
| Fish | Use lateral line system to detect acoustic signals at low frequency |
| Fish – In Tanks | Noise exposure influenced fat stores, growth and reproduction |
| Fish – Gold | Physiological stress, hearing loss from white noise |

| Species | Effects |
|---|---|
| Fish – Marine | Egg viability and fry growth rate reduced |
| Fish – Pink Snapper | Ear damage by loud LFN |
| Fish – Salmon | Respond to LFN particle motion |
| Flies – Diptera | Startle response to LFN |
| Fox | Avoid traffic at noisiest periods |
| Fox – Red | Slight reactors to LFN in feeding tests |
| Frog – Tree | Acoustic avoidance behaviour |
| Giraffes | Use infrasound for communication |
| Goats | Reduced milk yield |
| Guinea Pigs | Vascular, myocardium, conjunctiva, liver, metabolism and auditory changes |
| Hedgehog | Probable tactile response to LFN under 25Ohz |
| Hippopotamus | Use infrasound for communication |
| Insects – Aquatic | Numbers declined with increased traffic volume |
| Lizard – Mohave Fringe Toed Sand | Dune Buggy noise caused hearing loss |
| Mayfly | Concern over noise and vibration by wind turbine process on larvae |
| Mice | Lung damage and adrenal weight differences |
| Midges – Chironmidae | LFN acted as possible attractor |
| Moles | Retreat from 90dB+ sound source |
| Moose | Affected by traffic noise and caused displacement |
| Okapi | Use infrasound for communication |
| Pigs | Hormonal disturbance, water and sodium retention |
| Porpoises – Harbour | React to simulated, wind turbine water borne sound |
| Poultry | Reduced egg laying |
| Rat – Kangaroo | Hearing physiology affected by ORV noise |
| Rats | Vascular, myocardium, conjunctiva, liver, metabolism, auditory changes |
| Rats | Head and eye movement responses |
| Rats | Brain – slight impairment |
| Rhinoceros | Use infrasound for communication |
| Seals | Pregnancies aborted possibly due to pile driving |
| Seals - Harbour | Clicks increased by simulated wind turbine noise, surface at larger distance from sound source and leave area when ‘pingers’ operate |
| Sharks | Attracted by broad band low frequency regularly pulsed sounds (20Hz –100Hz) |
| Sheep and Lambs | Heart and respiratory rates increased and lowered feeding efficiency. |
| Shrimp – Brown | Reduction in reproduction and growth rates. Aggressive behaviour (cannibalism) |
| Snake – Adder | React to vibrations |
| Snake – Grass | React to vibrations |
| Squirrels | Avoid traffic at noisiest periods |

| Species | Effects |
|---|---|
| Squirrels – Ground | Enforced behavioural changes |
| Toad – Spadefoot | Confused by motorcycle noise – affects breeding |
| Weasels – Least | Sensitive to low frequencies |
| Whales | Avoid areas with sound commencing at 120dB |
| Whales – Singing Humpback | Disturbance, abandoned habitat including breeding, feeding and calving grounds |
| Whales – Sperm | Disturbance, abandoned habitat including breeding, feeding and calving grounds |

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# Toward a Case Definition of Adverse Health Effects in the Environs of Industrial Wind Turbines: Facilitating a Clinical Diagnosis

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# Toward a Case Definition of Adverse Health Effects in the Environs of Industrial Wind Turbines: Facilitating a Clinical Diagnosis

**Robert Y. McMurtry**[1]

**Abstract**

Internationally, there are reports of adverse health effects (AHE) in the environs of industrial wind turbines (IWT). There was multidisciplinary confirmation of the key characteristics of the AHE at the first international symposium on AHE/IWT. The symptoms being reported are consistent internationally and are characterized by crossover findings or a predictable appearance of signs and symptoms present with exposure to IWT sound energy and amelioration when the exposure ceases. There is also a revealed preference of victims to seek restoration away from their homes. This article identifies the need to create a case definition to establish a clinical diagnosis. A case definition is proposed that identifies the sine qua non diagnostic criteria for a diagnosis of adverse health effects in the environs of industrial wind turbines. Possible, probable, and confirmed diagnoses are detailed. The goal is to foster the adoption of a common case definition that will facilitate future research efforts.

**Keywords**

case definition, clinical diagnosis, wind turbines, adverse health effects, symptoms

## Introduction

On the last 3 days of October 2010, a groundbreaking meeting was held in the Waring House situated in Prince Edward County, Ontario (Society for Wind Vigilance, 2010). The focus of the symposium was the emerging issue of adverse health effects (AHEs) being experienced by people living in the environs of industrial wind turbines (IWTs).

These health effects appear to correlate with proximity to IWTs, the sound pressure level emitted by the IWTs, the frequency of the noise, the time of exposure, and individual response. The pattern of individuals' complaints demonstrates a striking similarity internationally in media reports and in physician-generated case series.

The issue of AHEs is of considerable complexity and has excited much controversy between proponents of the wind industry and those who have identified widespread media and Internet reports of AHEs in virtually all countries where IWTs have been erected (Gray, 2010; Jopson, 2010; Lam, 2009; Turkel, 2010).

The IWT proponents claim IWTs to be a promising green, clean, and free alternative source of electrical power and an ideal solution for reducing green house gases (Canadian Wind Energy Association, 2011; Nextera Energy Resources, 2010). Those who are concerned about IWT development too close to residences and who seek to prevent AHEs have a contrary view denying the foregoing claims and questioning the utility and safety of IWTs (Bryce, 2010; Gilligan, 2010).

This article will concentrate on the health aspects and the challenge of a case definition, leaving aside the debate surrounding economics, energy policy, lobbying, and social marketing, although all have a significant impact on government decision making.

## Overview of Conference and Speakers

The purpose of the symposium was to promote a multidisciplinary dialogue on possible AHEs in an effort to advance the understanding of the genesis of complaints appearing globally. Among the goals of the symposium was a need to develop a case definition, which had been under discussion since June 2010.

The symposium attracted a multidisciplinary international group of speakers (14), including the disciplines of medicine (four specialties), acoustics, psychology, business, physics,

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epidemiology, policy analysts, pharmacy, law, statistics, and media (Society for Wind Vigilance, 2010). There was also an informal research meeting of the speakers joined by two family physicians and an occupational health physician where a debriefing of the symposium was held and future plans for research made.

Approximately 100 people attended the symposium including municipal and federal politicians, media, documentary filmmakers, as well as two members of a leading consulting group for the industry and two representatives from a wind power developer. There was a notable absence of any representatives from the Ontario provincial government.

## *Brief Summary of Presentations*

The descriptions of the presentations below are highly abbreviated. The reader is referred to the Society for Wind Vigilance's website for more details.

Physics of IWTs and the resultant sound pressure level (SPL) are not adequately or consistently regulated. Based on experience with other noise sources, SPL clearly presents a health risk (Harrison, 2010; James, 2010; Walsh, 2010).

The human ear is perturbed by IWTs in quiet rural areas, potentially leading to neural remodeling and disorganization of neural pathways. It is more likely than not that the symptoms and signs associated with wind turbine syndrome are due to the sound energy emitted by IWTs. Low-frequency noise and infrasound will more likely than not be shown in subsequent research to be playing a major role in the genesis of wind turbine syndrome (Pierpont, 2010).

The outer hair cells of the cochlea respond to low frequency and infrasound. Sonic energy that is inaudible is perceived though not necessarily heard (except in sensitive people). What cannot be heard therefore may produce AHEs. This statement was made by Dr. Alex Salt, referring to his research using the standard animal model (guinea pig) for the study of human hearing (Salt, 2010).

Noise and infrasound during the day are capable of causing mood disorder, cognitive dysfunction, and learning and developmental problems in children. Stress and psychological distress are established findings of chronic exposure to noise. Chronic stress has serious physiological consequences (Bronzaft, 2010).

Nighttime noise compromises restorative sleep. Restorative sleep is a necessary condition for maintaining health and well-being. Chronic sleep disturbances (increased arousals and awakenings) and/or deprivation are established AHEs known to substantially increase the risk for chronic disease and premature death (Hanning, 2010).

Control studies comparing populations living near and far from IWT installations demonstrate a substantial and statistically significant difference in quality of life, mood disorders, and sleep disruption (Nissenbaum, 2010).

More than a hundred people in Ontario have self-identified as having AHEs using the Canada Vigilance protocol. AHEs with a very wide range of complaints were made, of which the most frequent are compromise of quality of life, sleep disruption, some living in the environs of IWTs leaving their homes temporarily or permanently in order to restore their health (Krogh, 2010). While some improvement in health status is achieved, follow-up has revealed that preexposure health status is not necessarily regained.

These findings are significant from a public health perspective for many reasons, including the findings the crossover and revealed preference in the WindVOiCe survey (Krogh et al., 2011). Crossover refers to the phenomenon of exacerbation and amelioration when near and far from wind farms, respectively. Revealed preference describes the act of leaving one's accustomed residence permanently or temporarily for significant periods of time in order to achieve restoration.

Legally there is evidence that the precautionary principle has not been respected by the governments who regulate and approve IWT installations in the absence of medical or health evidence establishing their safety (Gillespie, 2010). There is an urgent need to pursue research establishing dose-response curves as well as clinical research regarding psychological and physiological consequences (Bronzaft, 2010; Hanning, 2010).

There was a clear consensus among the foregoing presentations and from a wide variety of perspectives that AHEs are indeed occurring in relationship to people living in the environs of IWTs. In addition, an emerging consensus was evolving regarding a case definition that could be deployed by experts representing the many diverse disciplines in attendance. The importance of unifying the case definition for the purposes of research and future communications was clear.

## *Audience Response*

The symposium featured a learned and diverse group of speakers as noted above. Attendees were able to witness and participate in a successful event of transdisciplinarity. Regardless of discipline, a unity of perspective was achieved. AHEs are clearly an issue for people living in the environs of wind farms. While the precise mechanism for the cause of AHEs remains to be elucidated, there is enough evidence to conclude IWTs represent a public health threat. Audience members were also highly supportive of a unified case definition.

## *Summary*

The common denominator of the global reports of AHEs is the compromise of quality of life, restorative sleep, and psychological well-being.

There are many reports of AHEs in the environs of IWTs, including several case series (Harry, 2007). Unfortunately, no standard protocol for data gathering has been developed. This has lead to a wide variety of symptoms being reported and documented. This variance is exacerbated by the nonspecific nature of the complaints since the recorded symptomatology can arise from a wide variety of ailments and diseases.

The task of a case definition is to weight the unique elements of AHE/IWT to distinguish the clinical disorder from competing explanations. There are common themes found in the reports that are reflected in the first- and second-order criteria. There are few, if any, alternate explanations for the first- and second-order criteria other than AHE/IWT.

The third-order criteria serve the purpose of capturing the most commonly reported symptoms.

It is hoped that future reports will adopt a standardized protocol based on this case definition, which would facilitate future research and management of AHE/IWT.

## Case Definition

The criteria for making an individual diagnosis of probable AHEs in the environs of IWTs are presented in the following paragraphs. The definition endeavors to be specific and sensitive. While the definition has not been validated formally in practice, it has proven useful. The case definition represents an important starting point for future international research collaboration. The genesis of the definition is based on a review of the literature and direct experience with those individuals experiencing AHE/IWT. It has been used to provide guidance to physicians and other primary health providers when they are asked to manage individuals following exposure to IWTs. The value of this proposal is based on the absence of a specific case definition either in the peer-reviewed or gray literature.

### *Diagnosis of Adverse Health Effects in the Environs of Industrial Wind Turbines*

*Possible adverse health effects*. Report of a change in health status by people living within 5 km of a wind farm installation. Further confirmation is required to validate or exclude AHE/IWT by establishing a medical history that satisfies the criteria identified under "Probable Adverse Health Effects" below.

*Probable adverse health effects*.

1. First-order criteria (all four of the following must be present):
   - (a) Domicile within 5 km of industrial wind turbines (IWT)
   - (b) Altered health status following the start-up of, or initial exposure to, and during the operation of, IWTs. There may be a latent period of up to 6 months
   - (c) Amelioration of symptoms when more than 5 km from the environs of IWTs
   - (d) Recurrence of symptoms upon return to environs of IWTs within 5 km
2. Second-order criteria (at least three of the following occur or worsen after the initiation of operation of IWT):
   - (a) Compromise of quality of life
   - (b) Continuing sleep disruption, difficulty initiating sleep, and/or difficulty with sleep disruption
   - (c) Annoyance producing increased levels of stress and/or psychological distress
   - (d) Preference to leave residence temporarily or permanently for sleep restoration or well-being
3. Third-order criteria (at least three of the following occur or worsen following the initiation of IWTs):
   - (i) Otological and vestibular
     - (a) Tinnitus
     - (b) Dizziness
     - (c) Difficulties with balance
     - (d) Ear ache
     - (e) Nausea
   - (ii) Cognitive
     - (a) Difficulty in concentrating
     - (b) Problems with recall or difficulties with remembering significant information
   - (iii) Cardiovascular
     - (a) Hypertension
     - (b) Palpitations
     - (c) Enlarged heart (cardiomegaly)
   - (iv) Psychological
     - (a) Mood disorder, that is, depression, anxiety
     - (b) Frustration
     - (c) Feelings of distress
     - (d) Anger
   - (v) Regulatory disorders
     - (a) Difficulty in diabetes control
     - (b) Onset of thyroid disorders or difficulty controlling hypo- or hyperthyroidism
   - (vi) Systemic
     - (a) Fatigue
     - (b) Sleepiness

*Confirmed adverse health effects*. The confirmation of AHE/IWT is achieved by a clinical evaluation and physiological monitoring of individuals during exposure to IWT sonic energy or an accurate facsimile (recording or other imitative source of IWT sound). Ideally, sleep studies should be carried out in the home of people experiencing AHEs. The complex physiological monitoring equipment required for a sleep study is not readily made mobile. Accordingly, sleep studies need to be carried out in an established clinical sleep laboratory with a source of sonic energy that accurately reflects the person's exposure to IWTs.

The process may be simpler once controlled studies comparing possible victims with a nonexposed matched population are carried out. These studies could help determine the core physiological change(s) that is (are) likely occurring to those who live in the environs of IWTs.

The need to rule out alternate explanations is the responsibility of the licensed clinician. While adherence to the criteria has resulted in no false positive diagnosis to date further validation is required.

### Differential Diagnosis

Consideration should be given to other stressors present in the community. The most obvious is the wind itself, which when associated with substantial barometric changes is known to cause a variety of symptoms. In this case, the onset of AHEs would not correlate with the establishment of a wind farm nor would the AHEs improve when leaving the environs of a wind farm.

A second possibility is a stressful home environment, which might lead to restoration being more likely away from home. A history for family stressors should be elicited and ruled in or out. Another distinguishing feature is the absence of correlation with IWTs starting up or being in operation.

Psychological issues and/or mood disorders may be simultaneously or independently present. A key differentiating point is the timing of the onset and the impact of being away from home and the environs of IWTs. Significant improvement away from the environs of wind turbines and revealed preference for sleeping away from home serve to distinguish between AHEs due to IWTs versus an independent cause. If the situation appears more complex then a referral to a clinical psychologist or psychiatrist might be considered.

Apart from the foregoing, there are very few if any imitative AHEs that can meet the three orders of criteria outlined above. However, the author invites critical commentary that might indicate a different conclusion.

## Conclusions

1. A multidisciplinary symposium was held to address the possibility of adverse health effects in the environs of industrial wind turbines.
2. There was a consensus (unanimity) among the various experts that more likely than not, adverse health effects are occurring in the environs of industrial wind farms.
3. A case definition for adverse health effects in the environs of industrial wind turbines has been proposed based on the best available evidence. To date it has proven useful in clinical practice.
4. Further research is required to refine and validate the proposed definition and identify the simplest method by which to diagnose a confirmed case.

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## Bio

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# EDITORIALS

## Wind turbine noise

### Seems to affect health adversely and an independent review of evidence is needed

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The evidence for adequate sleep as a prerequisite for human health, particularly child health, is overwhelming. Governments have recently paid much attention to the effects of environmental noise on sleep duration and quality, and to how to reduce such noise.[1] However, governments have also imposed noise from industrial wind turbines on large swathes of peaceful countryside.

The impact of road, rail, and aircraft noise on sleep and daytime functioning (sleepiness and cognitive function) is well established.[1] Shortly after wind turbines began to be erected close to housing, complaints emerged of adverse effects on health. Sleep disturbance was the main complaint.[2] Such reports have been dismissed as being subjective and anecdotal, but experts contend that the quantity, consistency, and ubiquity of the complaints constitute epidemiological evidence of a strong link between wind turbine noise, ill health, and disruption of sleep.[3]

The noise emitted by a typical onshore 2.5 MW wind turbine has two main components. A dynamo mounted on an 80 m tower is driven through a gear train by blades as long as 45 m, and this generates both gear train noise and aerodynamic noise as the blades pass through the air, causing vortices to be shed from the edges. Wind constantly changes its velocity and direction, which means that the inflowing airstream is rarely stable. In addition, wind velocity increases with height (wind shear), especially at night, and there may be inflow turbulence from nearby structures—in particular, other turbines. This results in an impulsive noise, which is variously described as "swishing" and "thumping," and which is much more annoying than other sources of environmental noise and is poorly masked by ambient noise.[4 5]

Permitted external noise levels and setback distances vary between countries. UK guidance, ETSU-R-97, published in 1997 and not reviewed since, permits a night time noise level of 42 dBA, or 5 dBA above ambient noise level, whichever is the greater. This means that turbines must be set back by a minimum distance of 350-500 m, depending on the terrain and the turbines, from human habitation.

The aerodynamic noise generated by wind turbines has a large low frequency and infrasound component that is attenuated less with distance than higher frequency noise. Current noise measurement techniques and metrics tend to obscure the contribution of impulsive low frequency noise and infrasound.[6] A laboratory study has shown that low frequency noise is considerably more annoying than higher frequency noise and is harmful to health—it can cause nausea, headaches, disturbed sleep, and cognitive and psychological impairment.[7] A cochlear mechanism has been proposed that outlines how infrasound, previously disregarded because it is below the auditory threshold, could affect humans and contribute to adverse effects.[8]

Sixteen per cent of surveyed respondents who lived where calculated outdoor turbine noise exposures exceeded 35 dB LAeq (LAeq, the constant sound level that, in a given time period, would convey the same sound energy as the actual time varying sound level, weighted to approximate the response of the human ear) reported disturbed sleep.[4] A questionnaire survey concluded that turbine noise was more annoying at night, and that interrupted sleep and difficulty in returning to sleep increased with calculated noise level.[9] Even at the lowest noise levels, 20% of respondents reported disturbed sleep at least one night a month. In a meta-analysis of three European datasets (n=1764),[10] sleep disturbance clearly increased with higher calculated noise levels in two of the three studies.

In a survey of people residing in the vicinity of two US wind farms, those living within 375-1400 m reported worse sleep and more daytime sleepiness, in addition to having lower summary scores on the mental component of the short form 36 health survey than those who lived 3-6.6 km from a turbine. Modelled dose-response curves of both sleep and health scores against distance from nearest turbine were significantly related after controlling for sex, age, and household clustering, with a sharp increase in effects between 1 km and 2 km.[11] A New Zealand survey showed lower health related quality of life, especially sleep disturbance, in people who lived less than 2 km from turbines.[12]

A large body of evidence now exists to suggest that wind turbines disturb sleep and impair health at distances and external noise levels that are permitted in most jurisdictions, including

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the United Kingdom. Sleep disturbance may be a particular problem in children,[1] and it may have important implications for public health. When seeking to generate renewable energy through wind, governments must ensure that the public will not suffer harm from additional ambient noise. Robust independent research into the health effects of existing wind farms is long overdue, as is an independent review of existing evidence and guidance on acceptable noise levels.

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