On the Sharp Intake of Breath Preceding a Builder's Estimate

Joint Working Group on Estimating Acoustics (JWG-EA)

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Abstract

Before a builder names a price, the builder draws a sharp breath in through the teeth. This is not hesitation and it is not theatre; it is a measurement of the house. The in-drawn hiss is a burst of broadband noise ended by a click of the tongue, which is precisely the signal an acoustic engineer uses to measure how long a room takes to fall silent. The manner of that fall depends on the condition of the walls and ceilings: hollow plaster, damp masonry and hidden voids each alter it in a characteristic way. In structured interviews, master tradespeople could not say why they make the sound; asked what they were noticing, most described the room answering back. We recorded 1,906 domestic jobs at the builder's ears and found that the room's reply predicts the final invoice, and that everything the builder could see adds almost nothing to it. A vented dental splint left estimates intact; a sealed one tripled their error (ratio 3.1, 95% CI 2.6–3.7). Curtains and rugs, which change the acoustics of a room and nothing else about it, lowered the quote and left the invoice unchanged. The method fails in conservatories, and we do not know why. The builder is not hesitating. The builder is listening.

1 Introduction

The domestic estimate is preceded by a sound. The tradesperson enters the room, looks at the ceiling or the wall in question, draws air sharply inward across the incisors, and only then names a figure. The sound is so regular that it has become the emblem of the trade; it is imitated in comedy, anticipated by clients, and resented by consumer organisations, which interpret it as a device for preparing the client to accept a high number [7, 8].

That interpretation is mistaken. The intake of breath is not a manner of speaking about the job; it is the means by which the job is surveyed. A forceful dental ingressive fricative is a short burst of broadband noise. It is terminated, in nearly every recorded instance, by an abrupt lingual seal that produces a click. A burst of broadband noise with a hard stop is, to the letter, the excitation specified by the interrupted-noise method for the measurement of reverberation time [1]; the click supplies an impulse, the other excitation the method permits, at low frequency. The ears that receive the decay sit some fifteen centimetres from the mouth that produced it. The builder is, in the strict sense, a co-located source–receiver pair.

What the decay carries is the absorption of the room's surfaces, and absorption is not decorative. Plaster that has come away from its backing behaves as a panel absorber and removes energy near 200 Hz; saturated masonry reflects differently at high frequency from dry; a void behind a stud wall or above a ceiling couples a second volume to the first and bends the decay curve. These are the defects that determine what a job will cost, and they are the defects that cannot be seen.

This report establishes, across five studies, that the estimate is computed from the decay. Section 3 documents that expert estimators cannot articulate the cue they rely on, the signature of perceptual expertise. Section 4 formalises the survey. Section 5 shows that the decay predicts the invoice; that preventing the intake destroys estimating accuracy; that altering only the acoustics of a room alters its price; and that the recorded sound alone, heard by a builder who has never seen the room, is sufficient. Section 7 sets out the recommendations of the Working Group.

2 Background

2.1 Ingressive airstreams

Speech on the in-breath is well attested in several languages and dialects, most familiarly in the ingressive particle of agreement [2]. The dental ingressive fricative is not a speech sound in any language; it is a paralinguistic act. Its acoustic properties have nevertheless been described: turbulence at the incisal gap produces noise whose energy is concentrated between 2 and 10 kHz at levels of 60–72 dB(A) at one metre [2, 3]. No prior study has asked what the noise is for.

2.2 The interrupted-noise method

ISO 3382-2 permits two families of excitation for reverberation measurement: impulsive sources, and broadband noise that is switched off abruptly [1]. The decay following the switch-off is recorded and the time to fall 60 dB is extrapolated from the range -5 to -25 dB (T_{20}) or -5 to -35 dB (T_{30}). The method requires that the source and receiver be in the room and that the switch-off be fast relative to the decay. A domestic room has a reverberation time of 0.3–0.7 s; the closure of the tongue against the alveolar ridge is complete in under 20 ms.

2.3 Sounding

Inspection by excitation and listening is the oldest non-destructive test in construction. Bridge decks are

sounded with a hammer or a dragged chain, and delaminated concrete answers with a dull note [4]; aircraft composite panels are tapped with a coin for the same reason [5]; abrasive wheels are rung before mounting, and a cracked wheel does not ring. The collector who flicks a porcelain bowl with a fingernail is performing the same test on the same principle. In every case the inspector excites the structure deliberately and judges it by what returns. The present report moves the exciter from the hand to the mouth, and the structure from the object to the room in which the inspector stands.

2.4 The horn effect

A substantial literature treats the tradesperson's preliminary gestures as impression management. Clients who witness the intake of breath rate the subsequent estimate as less honest [7], and a negative impression formed by the sound spreads to judgements of competence, tidiness and punctuality, a classic horn effect [6]. That literature has measured what clients feel about the sound with some care. It has never measured the room.

3 Study 1: Cognitive Task Analysis

Expertise that operates through perception is characteristically inarticulate: the expert recognises a situation and acts, and the cue that drove the recognition is not available to report [9, 10]. If the intake of breath is a survey, those who make it should be unable to explain it, and should nevertheless describe its object when probed for cues rather than reasons.

Method. We conducted Critical Decision Method interviews [10] with 41 master tradespeople (general builders, plasterers, roofers and damp specialists; median 26 years in trade). Each participant nominated four estimates that had later proved either remarkably accurate or remarkably wrong, giving 164 incidents. Each incident was walked through chronologically; at the moment of the intake, interviewers applied the standard probes: *What were you noticing? What would a first-year apprentice have missed? What would have made you give a different figure?*

Findings. Asked directly why they make the sound, 38 of 41 participants could not say; the remainder offered that it was "habit" or "what you do". Asked instead what they were noticing at that moment, participants described the room. The cue inventory (Table 1) is dominated by auditory descriptors, overwhelmingly of the room's *reply* rather than its appearance. One plasterer with 31 years' experience described a ceiling as "too quiet for its size"; it was found to be detached from its laths across 70% of its area. A roofer described a loft conversion as "hanging on" after the sound; a void of 11 m^3 was later found behind the knee wall.

Two observations follow. First, the cues are the vocabulary of reverberation, described by people who have never been taught it. Second, the client's stated budget, the variable on which the theatre account depends, appears in four incidents of 164.

Table 1: Cue inventory from 164 Critical Decision Method incidents. A cue is counted once per incident.

Cue (coded from transcript)	Incidents	%
Room "answers back" / "comes back"	119	73
Room "too quiet" / "dead"	87	53
Sound "hangs" / "goes on"	64	39
Room "rings" / "hard"	41	25
Visible crack, stain or bow	52	32
Smell (damp, rot)	29	18
Client's stated budget	4	2

4 A Model of the Ingressive Survey

4.1 Excitation

Let the intake produce a noise burst $n(t)$ of duration τ_n, band-limited to $[f_\ell, f_h] \approx [2, 10]$ kHz, followed at $t = \tau_n$ by a lingual click $c(t)$ whose spectrum is approximately flat from 100 Hz to 4 kHz. The combined excitation $s(t) = n(t)\,\mathbf{1}[t < \tau_n] + c(t - \tau_n)$ thus covers the octave bands from 125 Hz to 8 kHz: the hiss serves the upper bands by interrupted noise, the click the lower bands by impulse.

4.2 Decay

In each octave band b excited by the click, the energy decay following τ_n is obtained by Schroeder backward integration of the band-filtered received signal $p_b(t)$,

$$E_b(t) = \int_t^\infty p_b^2(u)\,\mathrm{d}u, \tag{1}$$

and the band reverberation time T_b follows from the slope of $10\log_{10} E_b$. In the bands excited by the hiss the switch-off decay is read directly; Schroeder's integral is the ensemble average of such decays, and the two estimates coincide in expectation [11]. For a room of volume V and surfaces S_i with absorption coefficients $\alpha_{i,b}$, the Sabine relation [11] gives

$$T_b = \frac{0.161\,V}{\sum_i S_i\,\alpha_{i,b}}. \tag{2}$$

Equation (2) assumes a diffuse field. Below the Schroeder frequency, $f_s \approx 2000\sqrt{T/V}$ Hz, of order 200–300 Hz in a domestic room, the field is modal; at 125 and 250 Hz we therefore treat T_b as an empirical decay rate rather than a Sabine quantity, and use it only through its deviation from a reference room of the same volume (Section 4.4).

4.3 Defects as absorption

A plaster finish that has separated from its substrate forms a panel absorber whose resonance is

$$f_0 \approx \frac{60}{\sqrt{m\,d}}, \tag{3}$$

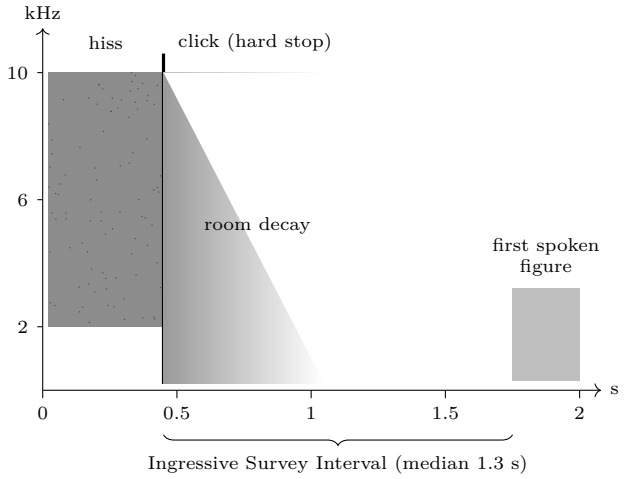


Figure 1: Anatomy of the intake (schematic, Study 2 median timings). Broadband hiss at the incisal gap is terminated by a lingual click; the decay of the room follows, and the figure is spoken only after it is complete.

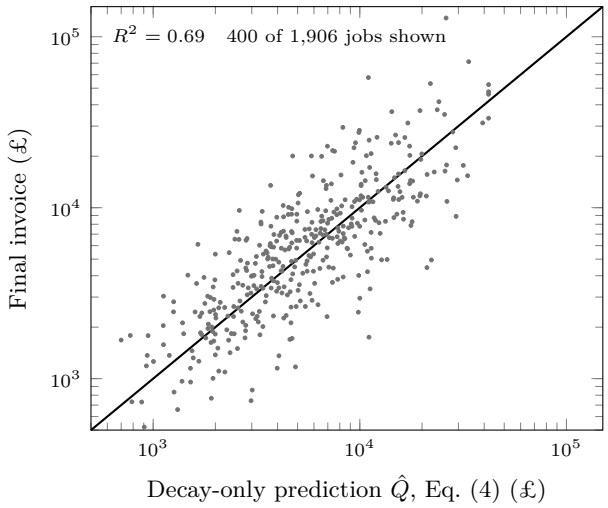


Figure 2: Study 2. The final invoice against the cost predicted from the decay of the room alone. Line: identity. Adding photographic defect coding raises R^2 by 0.004.

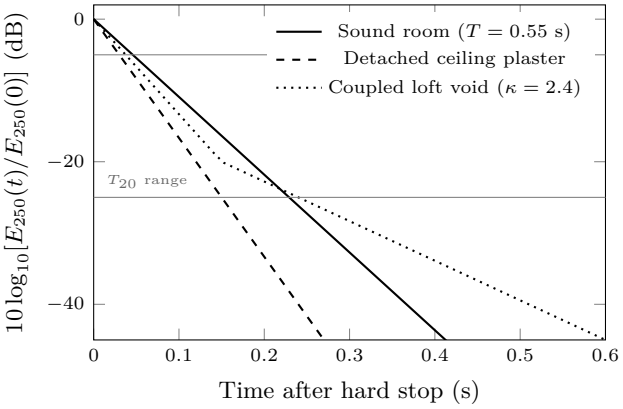


Figure 3: Representative Schroeder decay curves (Eq. (1)) in the 250 Hz band for three rooms of similar volume in Study 2. Detached plaster steepens the decay; a coupled void bends it.

with m the surface mass in $\mathrm{kg\,m^{-2}}$ and d the cavity depth in metres. For 12.5 mm of lime plaster ($m \approx 20$) detached by 5 mm, $f_0 \approx 60/\sqrt{0.1} \approx 190$ Hz; a detached area therefore shortens T_{125} and T_{250} in proportion to its extent. Moisture in porous masonry lowers its high-frequency absorption, raising $T_{4\mathrm{k}}$ and $T_{8\mathrm{k}}$. A concealed volume V_2 coupled to the room through an aperture produces a double-slope decay, which we summarise by the ratio $\kappa = T_{\mathrm{late}}/T_{\mathrm{early}}$ of late to early slopes [12].

4.4 Estimator

For each room we define the deviation of each band from the reverberation time expected of a sound room of the same volume and finish class, $\Delta_b = \log(T_b/T_b^{\mathrm{ref}}(V))$. The survey estimator is then

$$\log \hat{Q} = \beta_0 + \beta_1 \log V + \sum_b \gamma_b \, \Delta_b + \delta \log \kappa, \qquad (4)$$

where $\hat{Q}$ is the predicted cost of the job. The fitted γ_b are negative at 125 and 250 Hz, where a short decay indicates detached plaster, and positive at 4 and 8 kHz, where a long decay indicates damp. Equation (4) is not proposed as what the builder computes; it is proposed as what the builder's figure can be shown to contain.

The interval between the hard stop and the first spoken figure, which we term the *Ingressive Survey Interval* (ISI; Figure 1), had a median of 1.3 s across Study 2, roughly twice the upper end of the domestic range of reverberation time. The builder speaks only after the room has fallen silent.

5 Studies 2–5

5.1 Study 2: instrumented cohort

Three hundred and twelve builders wore head-mounted binaural microphones for all estimating visits over eighteen months. We retained 1,906 jobs for which a single room was quoted, the quote was accepted, and a final invoice was issued. Band reverberation times and κ were extracted from the decay following each intake. In parallel, two independent surveyors coded every visible defect from photographs taken at the visit.

Equation (4), fitted on the decay alone, explains 69% of the variance in log invoice (Figure 2); the builder's own quote explains 70%. The decay features carrying the prediction are those of Section 4: band deficits at 125–250 Hz and double-slope ratios (Figure 3). Adding the photographic defect coding to the decay model raises the explained variance by 0.4 percentage points. Everything the builder could see is already in what the builder heard.

5.2 Study 3: occlusion trial

If the figure is computed from the decay, preventing the excitation should degrade it. Ninety-six builders wore one of two custom dental splints at each estimating visit, the splint being randomised within builder and across jobs (588 jobs). The splints were identical in fit and appearance. One was vented at the incisal edge

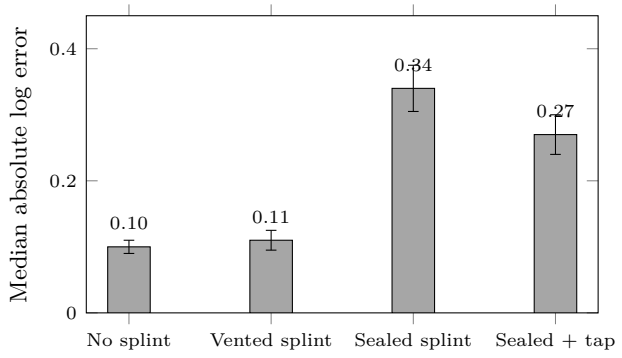


Figure 4: Study 3. Error of the quote against the eventual invoice by splint arm (588 jobs, 96 builders; no-splint reference from Study 2). Whiskers: 95% intervals.

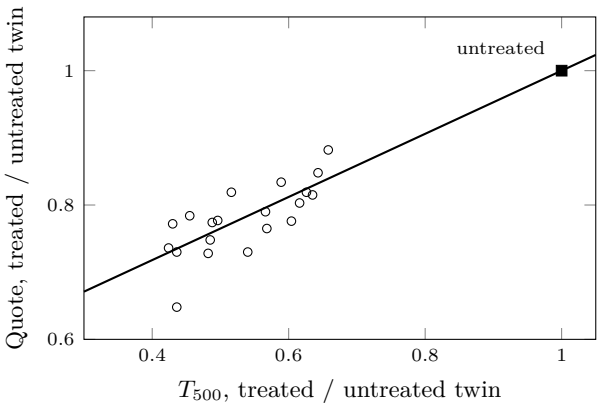


Figure 5: Study 4. Twenty matched pairs of rooms awaiting identical work. Curtains and rugs shortened the decay of the treated room, and its quote fell with it. Invoices did not differ.

and permitted the ingressive fricative; the other was sealed and did not. Builders were told that the study concerned bruxism and were not told that the splints differed; clients could not distinguish the arms.

Under the vented splint the median absolute log error of the quote against the eventual invoice was 0.11, indistinguishable from unsplinted visits in Study 2 (0.10). Under the sealed splint it was 0.34: a ratio of 3.1 (95% CI 2.6–3.7; Figure 4). Builders in the sealed arm were observed to make the attempt in 91% of visits, to look at the ceiling for longer, and to tap the wall with a knuckle. The knuckle, an exciter of the kind described in Section 2.3, recovered some of the deficit (Table 2).

5.3 Study 4: acoustic treatment trial

Study 3 removes the instrument. Study 4 leaves the instrument in place and alters only what it measures. In 20 matched pairs of rooms scheduled for identical replastering, the Working Group hung heavy wool curtains and laid rugs before the estimating visit in one room of each pair, chosen at random, raising total absorption without altering the fabric, the defects, or the scope of works. Each room was quoted by six builders independently.

The treated rooms had a mean T_{500} of 0.31 s against 0.62 s for untreated rooms. They were quoted 23% lower, and within each pair the reduction scaled with the shortening of the decay (Figure 5). Their invoices, for identical work, did not differ. Heavy textiles absorb strongly above 250 Hz and little at 125 Hz. The treatment therefore left nearly unchanged the low bands, in which detached plaster is read, and shortened the middle and upper bands, in which a short decay is the signature of dry masonry and in which the late slope of a coupled void is lost. The builders heard a sounder room than the one they were standing in, and priced the room they heard.

5.4 Study 5: playback

Fifty-eight blindfolded builders heard, through calibrated headphones, recordings of the intake and its decay made in 220 rooms they had never visited, with the volume of each room stated aloud. Their spoken estimates correlated with the eventual invoices at $r = 0.71$ (95% CI 0.64–0.77). Shown photographs of the same rooms without sound, the same builders achieved $r = 0.38$.

Table 2: Summary of interventional studies. MALE: median absolute log error of quote against invoice.

Study	Condition	Result
3	No splint (Study 2 ref.)	MALE 0.10
3	Vented splint	MALE 0.11
3	Sealed splint	MALE 0.34
3	Sealed + knuckle tap	MALE 0.27
4	Untreated room	quote = 1.00
4	Curtains and rugs	quote = 0.77
5	Sound only, blindfolded	$r = 0.71$
5	Photographs only	$r = 0.38$

6 Discussion

The five studies converge. The estimators cannot say what they attend to and describe, when probed, the decay of a room. The decay predicts the invoice and absorbs the predictive content of everything visible. Removing the excitation triples the error; altering the room's acoustics alone moves the price; and the sound alone, without the room, suffices. There is no account on which the intake is theatre that survives Study 4, in which the theatre was unchanged and the price moved, or Study 5, in which there was no client to perform for.

The horn-effect literature is not wrong about clients; it is wrong about what clients are reacting to. The sound precedes a high number because the sound is the means by which the high number is found. A client who hears it and concludes that the builder is preparing them for bad news has drawn the correct inference from the wrong model.

Limitations. The method fails in conservatories. In the glazed rooms of Study 2 the decay bore no relation to the invoice ($R^2 = 0.03$); builders in Study 1 described such rooms as "saying nothing"; and in Study 5

estimates for them from playback did no better than chance. A glass enclosure is highly reflective and its decay should be, if anything, easier to read. We do not know why it is not. Open-plan dwellings were excluded, as the decay of a single quoted area cannot be isolated from its neighbours. Builders with upper respiratory infections were excluded on the advice of our ethics committee, and we report no data on them.

7 Recommendations of the Working Group

1. Consumer guidance that characterises the intake of breath as a negotiating tactic should be withdrawn.
2. Clients should not speak, run taps, or operate appliances during the Ingressive Survey Interval.
3. Rooms should be quoted unfurnished, or the quote annotated with the soft furnishings present.
4. Apprentice training should include supervised intake in rooms of known condition from the first year.
5. Conservatories should be surveyed by other means until the failure described above is understood.

8 Conclusion

The sharp intake of breath is a reverberation measurement made with the only instrument a tradesperson is certain to have brought. It has been mistaken for an expression because it is made with the face. The figure that follows it is a reading; the clients who resent it, and the guidance that teaches them to, are objecting to the survey and not to the surveyor. Rooms will continue to answer whether or not anyone is listening, and the cost of the work will continue to be in the answer.

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