Perception Enhancement for Automotive Steering Systems

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Perception Enhancement Systems

Brunel Design

Advanced Steering Systems Conference

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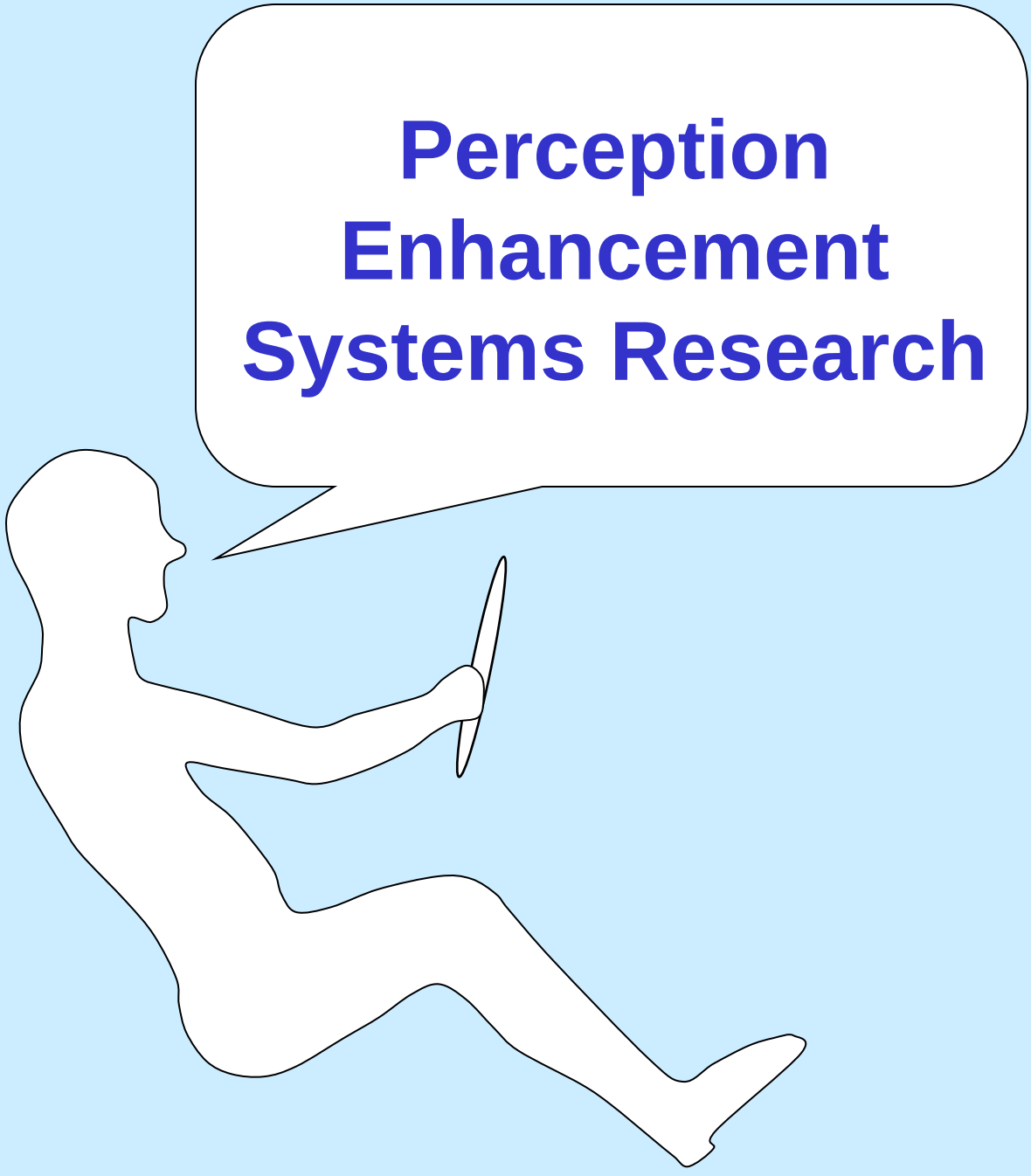
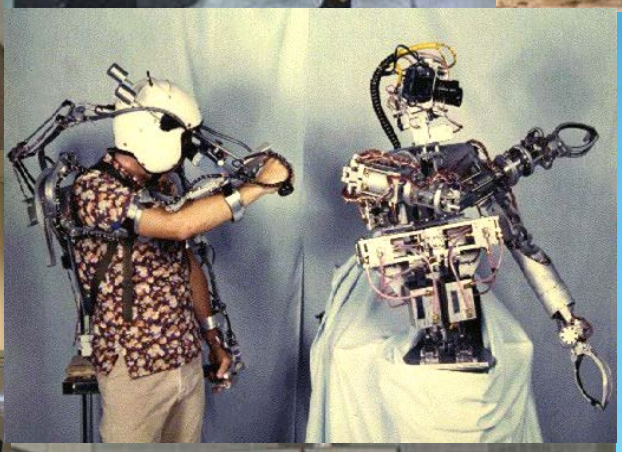
April 10-12 2006

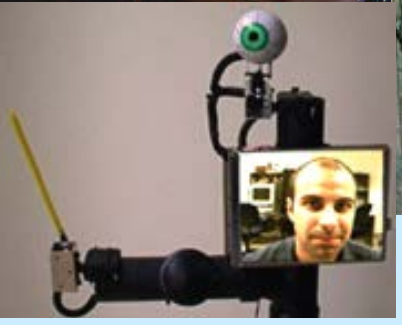
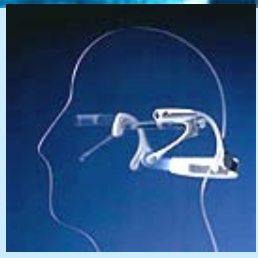

Perception
Enhancement
Systems Research



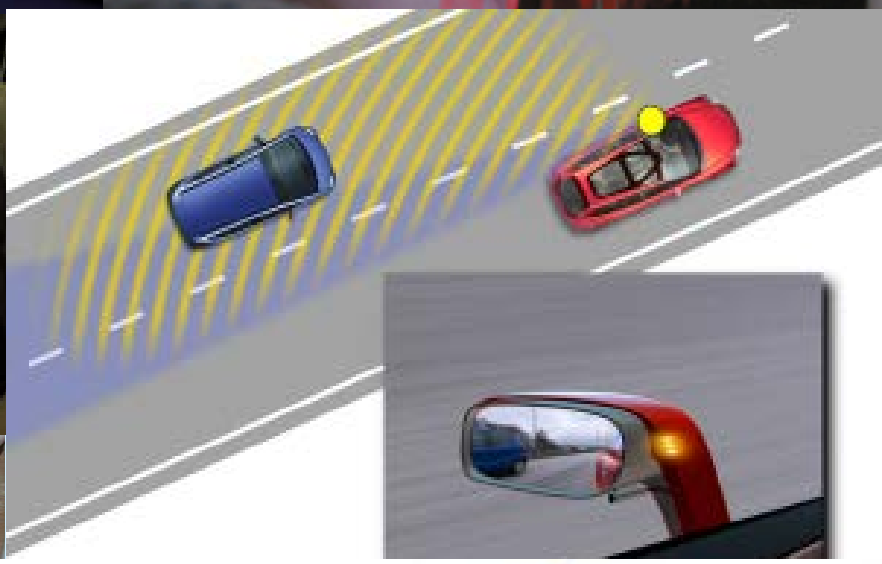


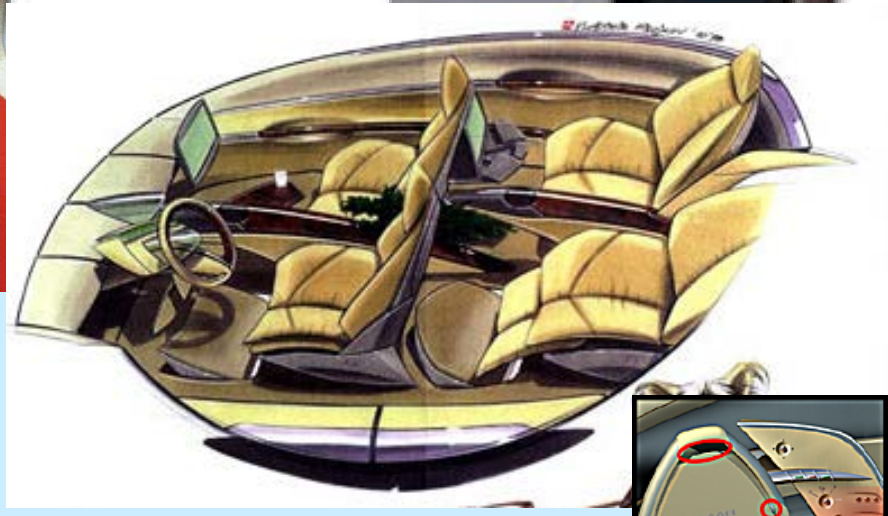


Person-Machine Integration

Many systems are under development which blur the traditional distinctions between machine and human.





Person-Machine Integration

In road vehicles new interfaces are being developed which integrate the functions of humans with those of the machine.

What is Perception Enhancement ?

The concept of perception enhancement emerges from the observation that not all machine emissions are informative. Only certain cognitively-relevant features from the environment have meaning for humans.

This goal is therefore to design engineering systems which selectively amplify the key environmental phenomena so that humans can better interact with their machines and automated assistants.

Perception Enhancement

The concept of Perception Enhancement is not a new one, at least not in the areas of vision and optics. Optic lenses were already in use in Roman times, as evidenced by the reducing lens and by the enlarging lens below.

◆ **4.5. Lente piano concava**

Cristallo di rocca
Diam. cm 2,48
Provenienza: Efeso
Londra, British Museum, inv. 1907.12-1.472

Lente piano concava scavata a Efeso, in Asia Minore, particolare per la caratteristica di ridurre l'immagine piuttosto che ingrandirla. La superficie del cristallo, levigata e trasparente, è ancora ben conservata e mette in evidenza caratteristiche ottiche di notevole efficacia.

Bibliografia: TEMPLE 2000, p. 403.

◆ **4.9. Lente**

Cristallo di rocca, incolore
cm 2,1 x 2,4; spessore cm 0,6
Provenienza: sconosciuta, forse dall'area vesuviana
SANC inv. 155902
I secolo d.C.

Di forma ovale, perfettamente integra, ha una faccia piana e levigata e quella opposta convessa, producendo l'effetto di lente di ingrandimento. Negli scavi borbonici a Pompei è segnalato il rinvenimento di parti di lastrine di vetro (o cristallo) tagliate in maniera tale da farne ipotizzare analoga funzione (*POMPEIANARUM ANTIQUITATUM* 1860, parte III, p. 88).

Bibliografia: inedito.

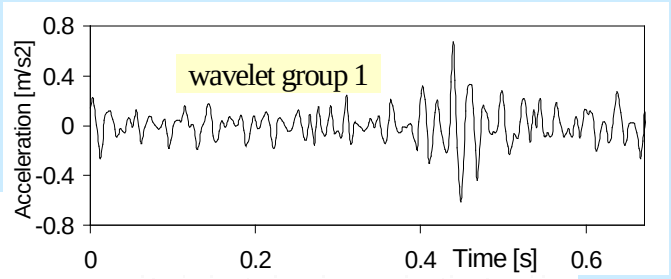
MRB

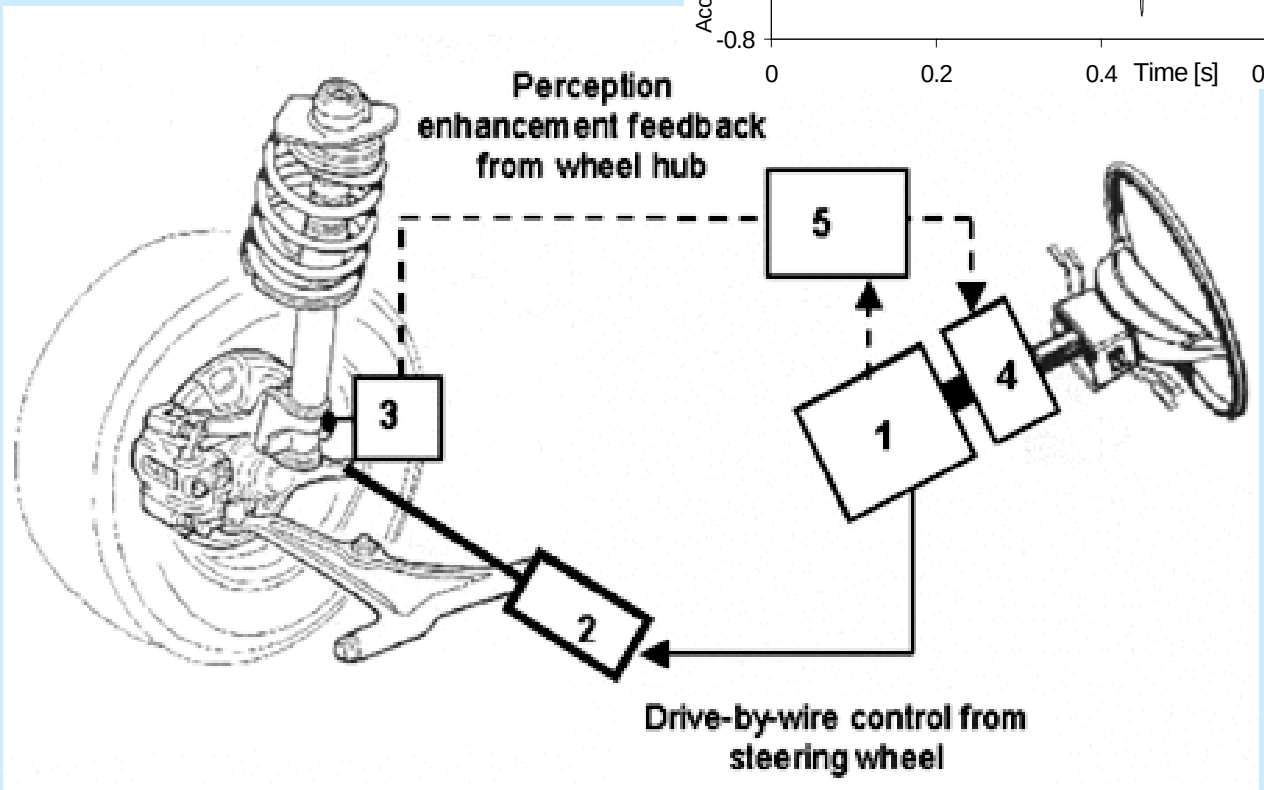
Perception Enhancement Systems

A more recent development, however, is the ability of new technology to provide sophisticated systems for modifying environmental stimuli to suit human needs. Such *Perception Enhancement Systems* provide the opportunity for improving the human condition, as evidenced by the night vision system shown below.

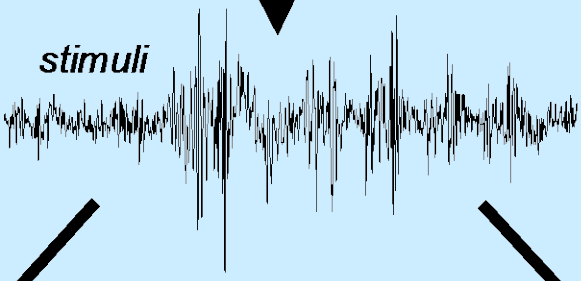
Perception Enhancement Systems

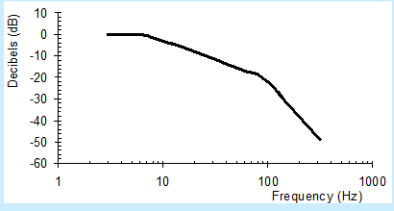
The term *Perception Enhancement System* can be used to describe any device which optimises the feedback to the driver of information about vehicle interaction with the environment. Such systems treat the data from an information theoretic point of view, and optimise the person-machine interface so as to make the vehicle feel more like an extension of the driver's body.



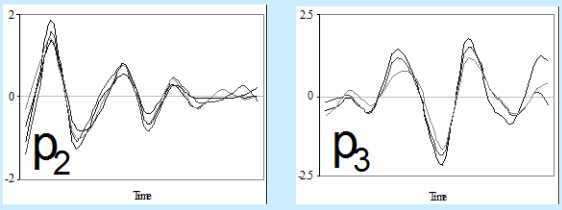


Comfort Versus Information





frequency weightings and psychophysical transformations



extraction of cognitively relevant features

$$VDV = \left[\int_0^T a^4(t)\,dt \right]^{\frac{1}{4}}$$

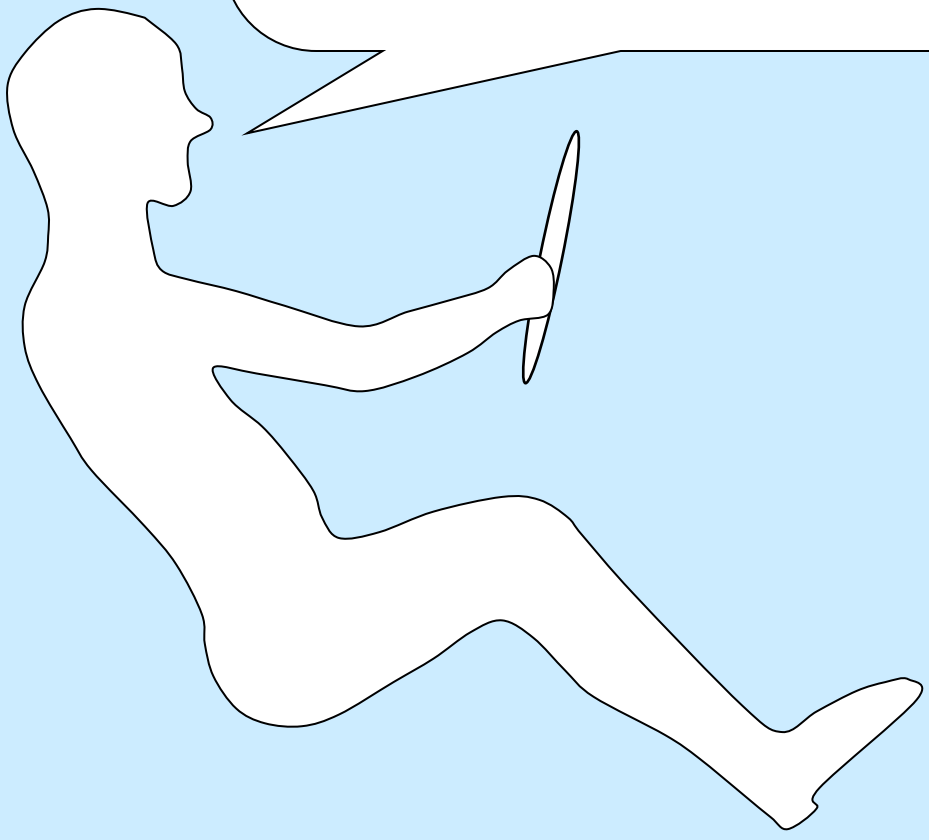
statistical measures of comfort

$$H = -\sum_{i=1}^{n} p_i \log p_i$$

statistical measures of information

comparison of comfort and information values

Perception Enhancement Principles from Audio Mastering



What is Audio Mastering ?

Audio mastering is the last creative step in the process of producing a record album. It occurs after the mixing of the various recorded sound channels, and just before the album is sent for manufacturing.

Mastering is the last opportunity for fixing any problems and for enhancing a music recording.

Mastering Audio

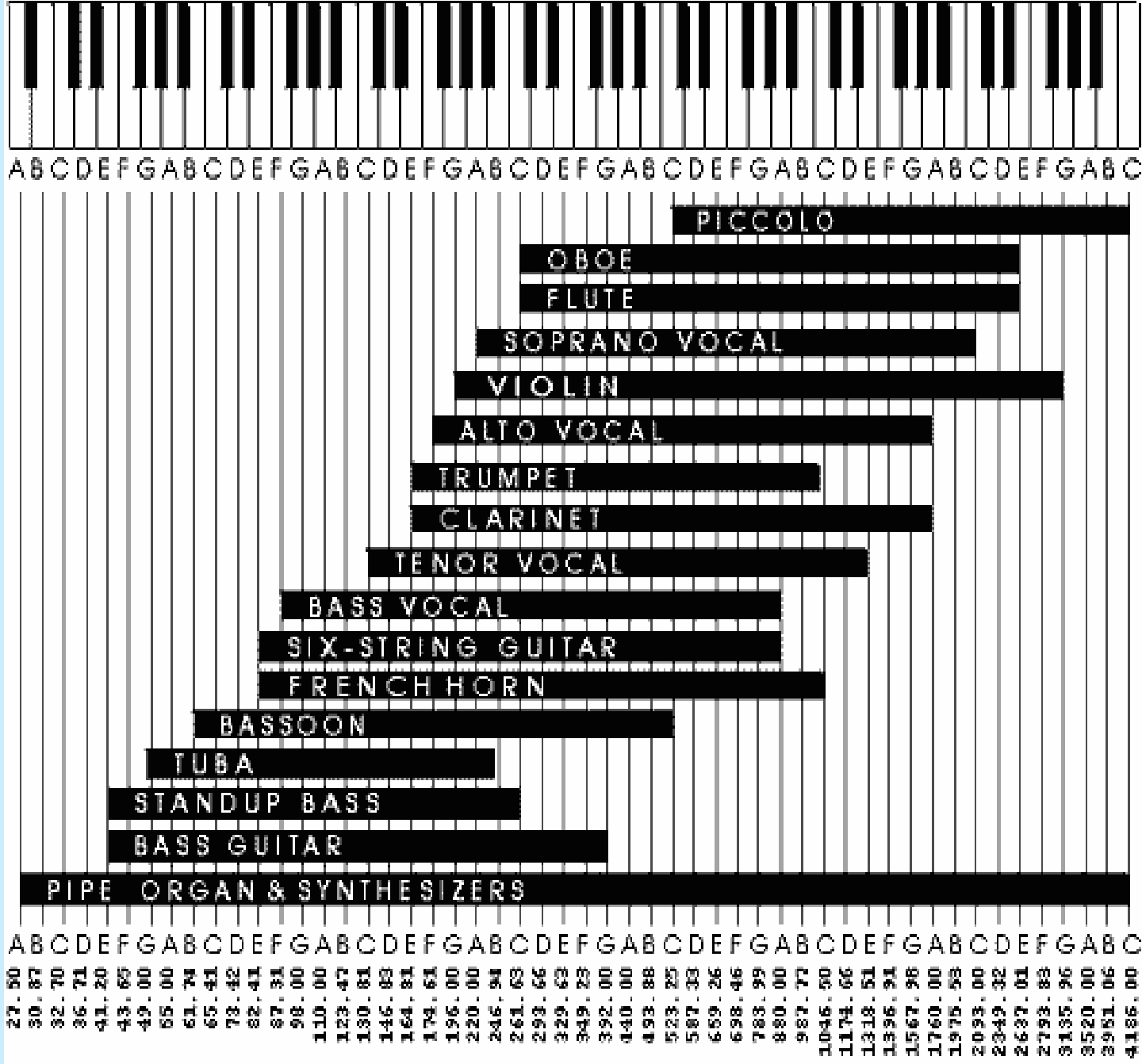
the art and the science

Audio mastering is more of an art than a science, because the optimal sound signal transformations depend on the desired emotional response of the listener.

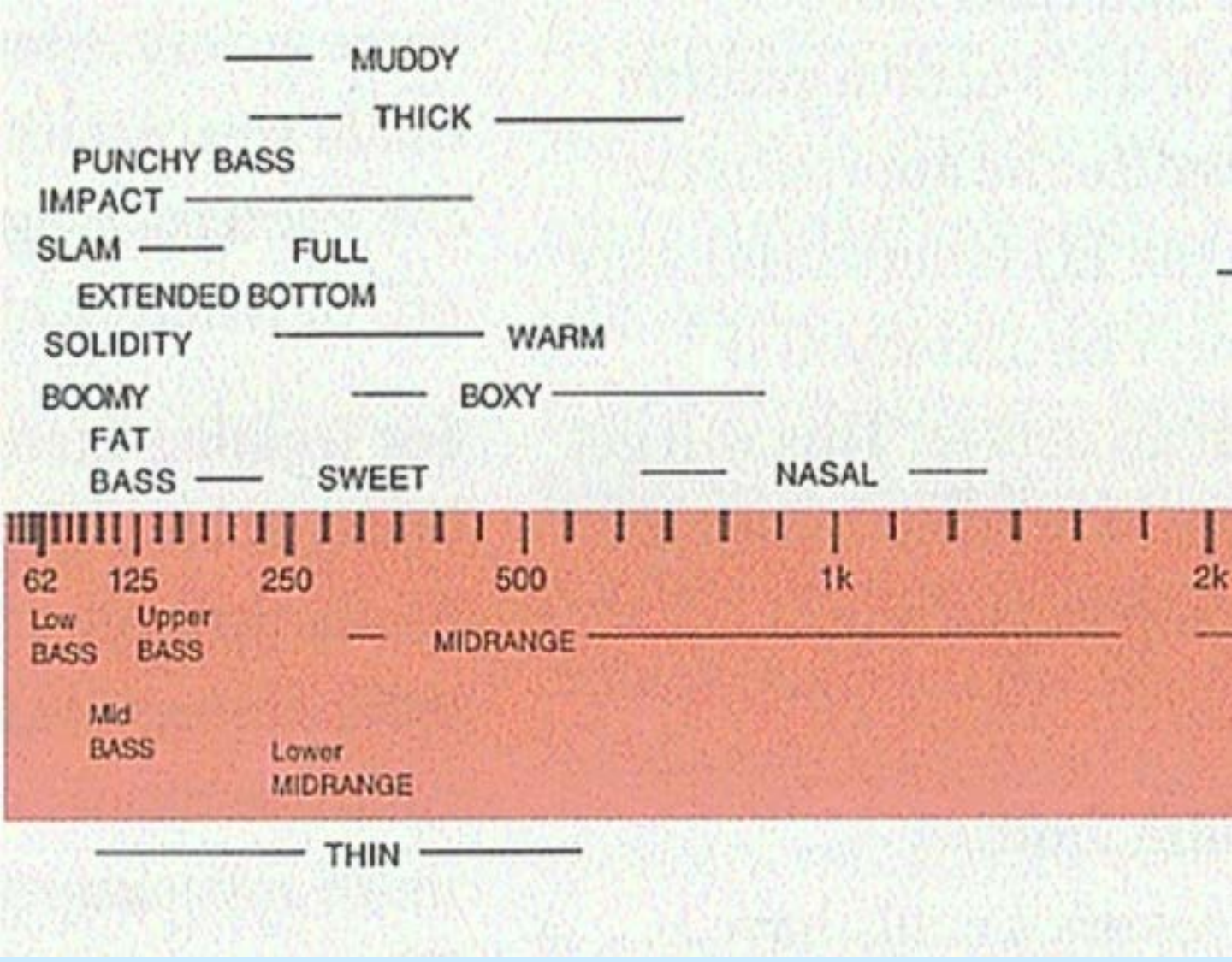
Objectives of Audio Mastering

In audio mastering, some of the most common signal processing operations which are performed include:

- **Analog to digital conversion**
- **Digital to analogue conversion**
- **Equalization**
- **Noise reduction**
- **Addition of special effects**



Reference frequency and amplitude ranges of the musical instruments are used when deciding parameter settings for equalizers, filters and special effects.



Reference semantic descriptors are used for the subjective sensations associated with deficiency or excess of sound energy in the various frequency ranges.

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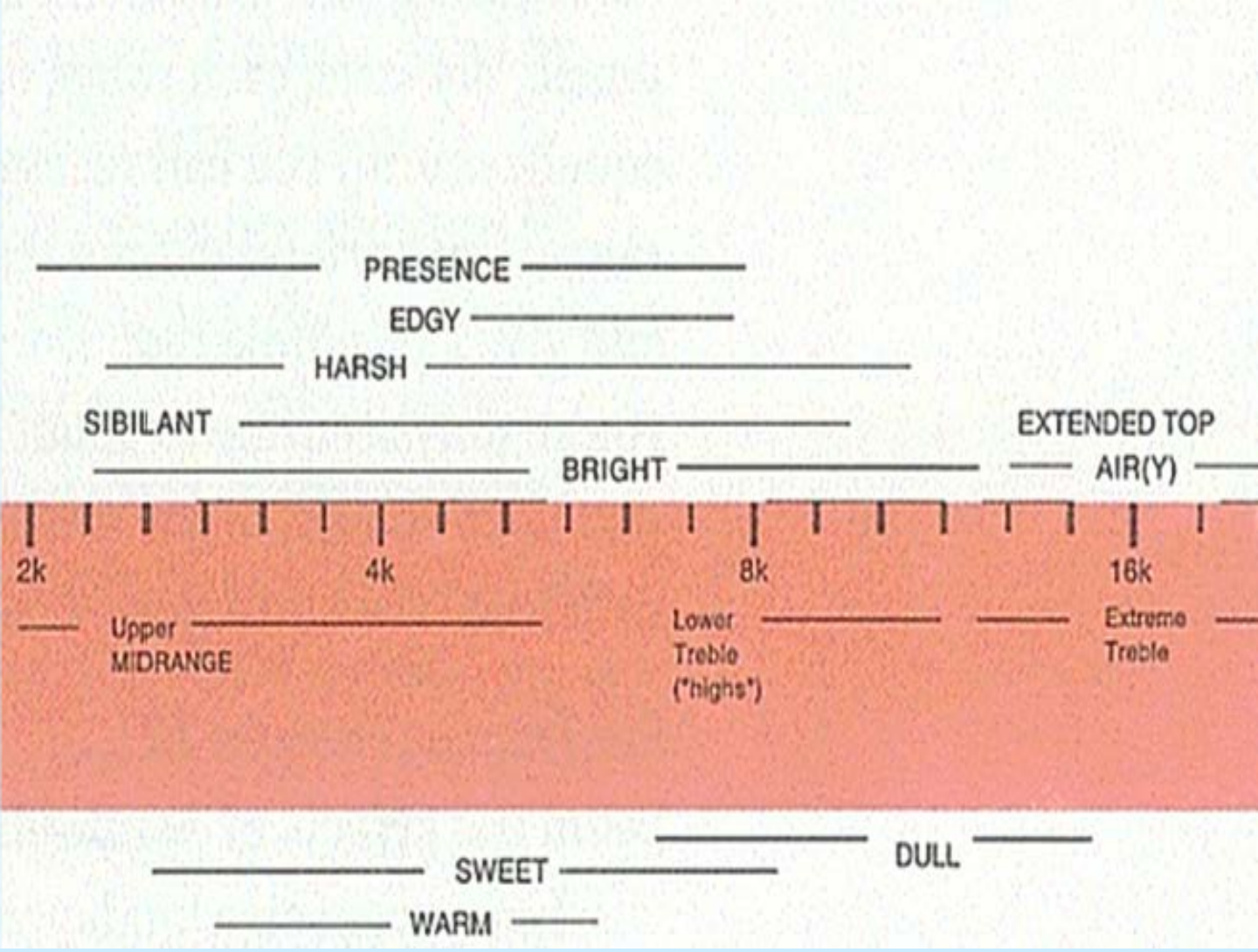


KICK

boost 80Hz
cut 200Hz
establishes low end for whole song
thump chest 100-200Hz
i.e. low cut 35Hz boost 95Hz midbass cut 160Hz hgh shelf cut few dBs
cuts in 200-400hz, narrow Q cuts at 160, 800 and 1.3Khz
compression 4:1 fa mr 6db of gain reduction
5-7Khz for snap
Floppy at 600 Hz. Boomy below 80 Hz. Slap at 2-5 KHz. Bottom at 60-125 Hz. For most pop music, remove the front head, then put a heavy blanket inside resting against the front head.

SNARE

fundamental 200-300Hz
range 200-800Hz
cut below 150hz
cut Q at 400,800,1.3khz
boost at 5kHz and brighten at 10kHz
Annoying at 1 KHz. Crisp above 2 KHz. Full at 150-200 Hz. Deep at 80 Hz. Also try adjusting the tightness of the snare wires.

Recommended gain, filter and special effects settings exist for use with the various sound channels.

Bass Guitar

boost 150Hz
establishes low end for whole song
bass midrange 800Hz-2kHz
roundness 60-150Hz
pop'n'snap 2.5-3khz
cut 250Hz?
clarity at 800Hz
roll off below 150Hz,mold mids then bring up lows for power
Thin at 1 KHz. Boomy at 125 Hz. Growl at 600 Hz. Bottom below 80 Hz. Sound varies greatly depending on the type of bass and brand of strings used.
String Bass Hollow at 600 Hz. Boomy at 200 Hz. Slap at 2-5 KHz. Bottom below 125 Hz.

GUITAR

boost low mids at 400MHz for warmth
boost 3kHz for edge/punch
fundamentals 400-800Hz
low shelf cut 400Hz lower mud factor
rhythm guitar compression 7:1 fast attack/med release
rhythm caoustic lower 80-240hz
cut out all below 80Hz
1-5khz verify
Electric Muddy below 80 Hz. Clarity at 3 KHz. Bottom at 125 Hz.
Acoustic Tinny at 2-3 KHz. Boomy at 200 Hz. Sparkle above 5 KHz. Full at 125 Hz.

20Hz 40Hz 60Hz 100Hz 200Hz 500Hz 800Hz 1kHz 2kHz

PIANO

cut out all below 80Hz
1-5khz verify
Tinny at 1-2 KHz. Boomy at 300 Hz.
Presence at 5 KHz. Bottom at 100 Hz.
Don't add too much bottom when mixing with a full rhythm section.

VIOLIN

Horns and Strings Scratchy at 3 KHz. Honky at 1 KHz. Muddy below 120 Hz. Hot at 8-12 KHz. Clarity above 2 KHz. Strings are lush at 400-600 Hz.

Male Vocal

Female Vocal

low cut at 75Hz when recording /
boost at 1-5kHz for presedince (5 better)
fundamentals 800-1kHz
thicker 150-260Hz
high pass filter when recording
re cut at 1-3khz, presence 5-7kHz, 10-12 air and sparkle
Reverb 1.5-2.5 seconds
Delay >250ms or 30ms to double the vocal
compression 3:1 mid attack/release

Scratchy at 2 KHz. Nasal at 1 KHz. Popping Ps below 80 Hz. Hot at 8 KHz. Clarity above 3 KHz. Body at 200-400 Hz. Aim for a thinner sound when blending many voices, especially if the backing track is full.

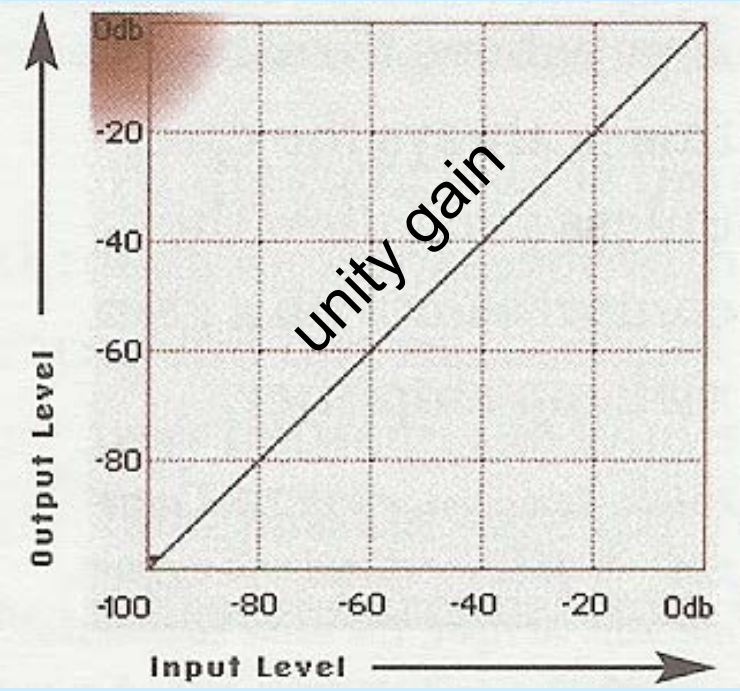
FLUTE

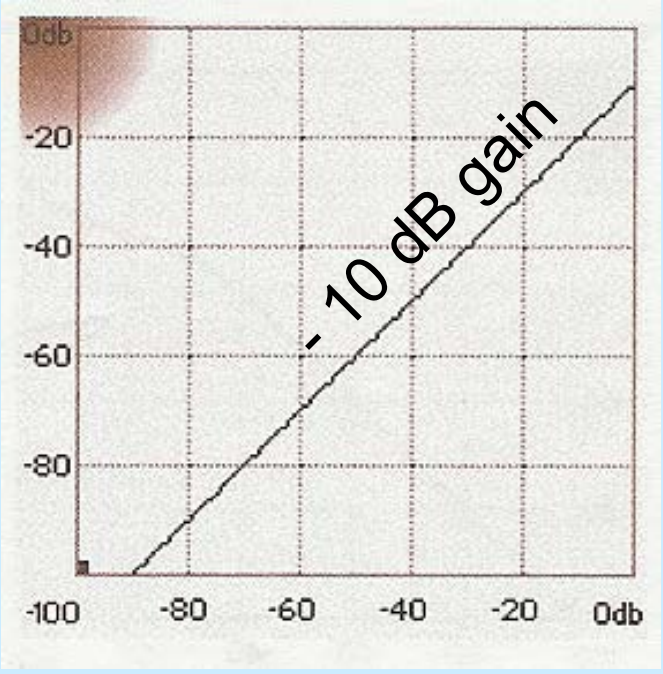
HITS

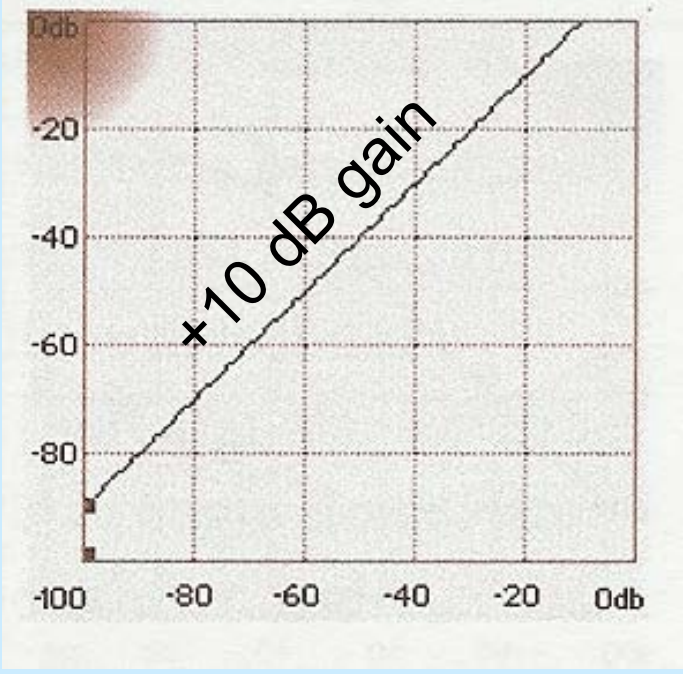
cymbals EQ at12.5kHz shelving EQ
hi-hats low cut 100Hz (200hz) high boost 8kHz
400-1kHz important, 600-800 best
toms cut at 300-800Hz
cut all below 100Hz
Toms Boomy at 300 Hz. Slap at 2-5 KHz. Bottom at 80- 200 Hz.
Tuning and adjusting the head tension makes a huge difference too!
Cymbals, bells, tambourines, etc. Annoying at 1 KHz. Sparkle above 5 KHz. [Analog only:] Record these instruments at conservative levels, especially at slower tape speeds.

Scale/Gain Changers

Scale/Gain changers are simple scaling operators which multiply the complete sound time history by a constant scalar value.



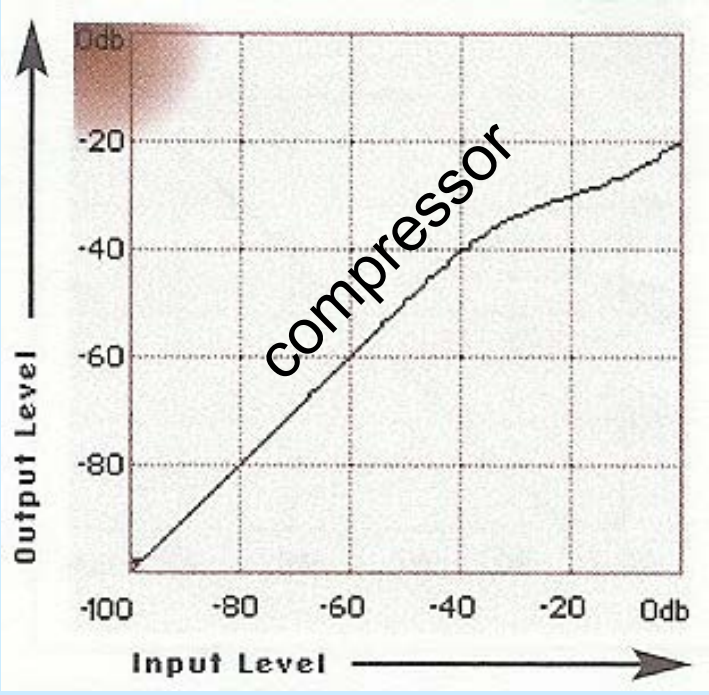


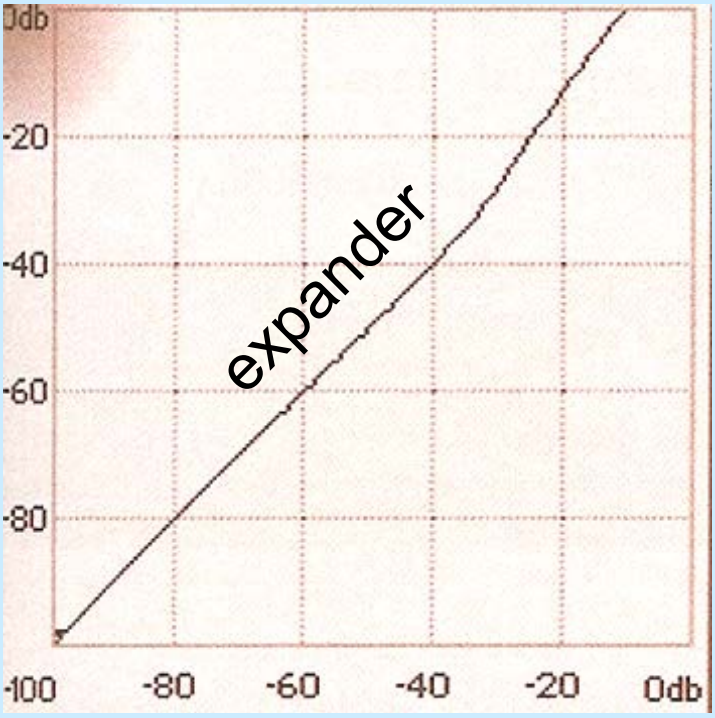


Compressors and Expanders

Compressors and expanders are used to modify the scale relationships of the data points of sound time histories.

The complete sound time history is multiplied by scalar values which are amplitude dependent.



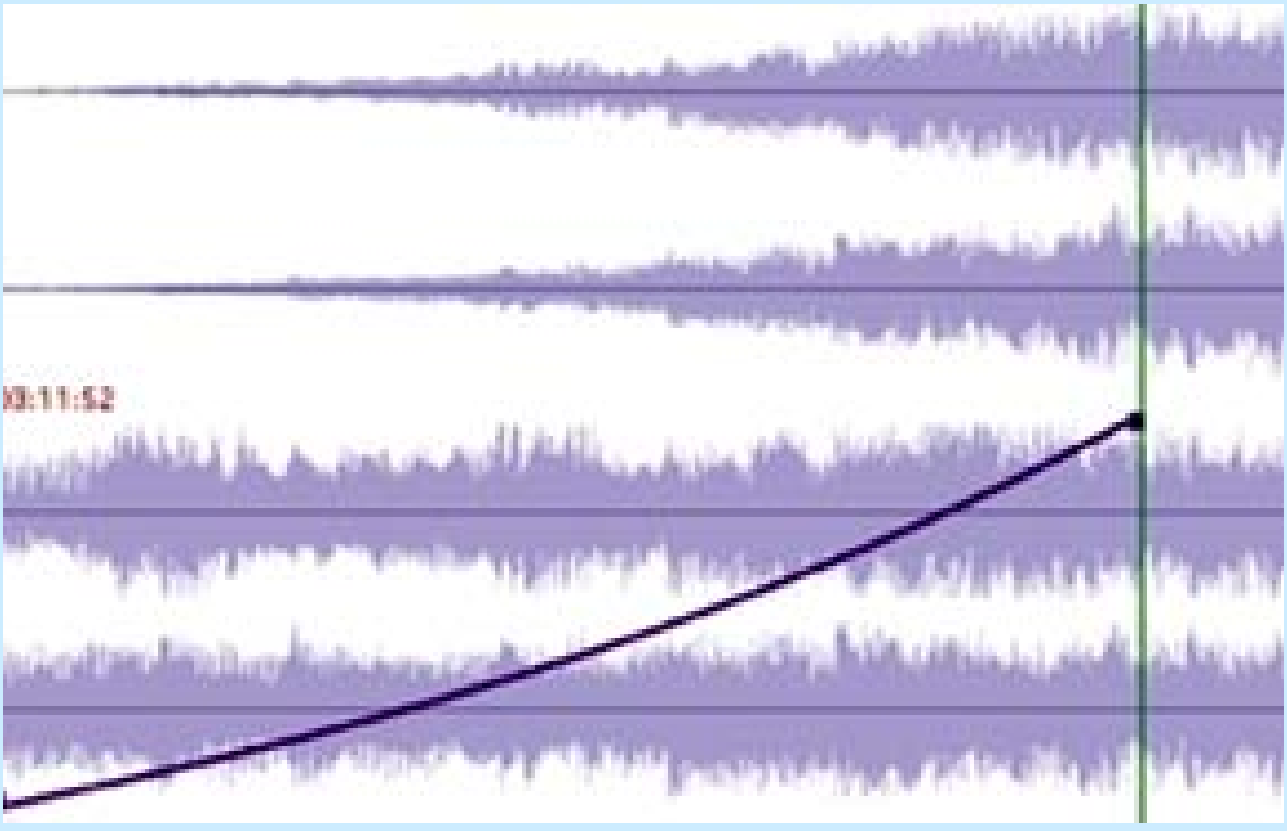


Effects of Compressors/Expanders

DOWNWARD COMPRESSION	UPWARD EXPANSION
makes sound louder during the **descent** of the music (release phase).	makes sound louder during the **rise** of the music (attack phase).
tends to make sound fatter and exaggerate low frequencies (subject to time constants and threshold).	tends to exaggerate transients and high frequencies (subject to time constants and threshold).
Attacks that are too short (fast) cause transients to be lost.	Attacks as short as a few ms can restore and sharpen lost transients (e.g., from analog tape or overcompressed sources).
Typical attacks 100 ms through 300 ms. Less than 100 tends to blur transients.	Typical attacks 1 ms through 300 ms. If a transient still sounds too sharp and trying >150 ms attack, perhaps this is not the right process for this music, or consider a touch of limiting after the expansion.
tends to make things sound duller or warmer.	tends to make sounds brighter or sharper.
If sounds "jump out" too much, raise the ratio, shorten the attack, and/or speed up the release.	If sounds "jump out" too much, lower the ratio, lengthen the attack, and/or slow down the release.
If attacks seem too sharp, shorten the attack time.	If attacks seem too sharp, lengthen the attack time, or consider compression.
If sustains seem too long or too prominent, lengthen the release time.	If sustains seem too short, lengthen the release time.
If attacks seem too dull, lengthen the attack time.	If attacks need enhancement, shorten the attack time.
If you don't like the percussiveness (e.g., snare drum), speed up the attack. To increase the ratio of rhythm to melody, lengthen the attack. Downward compression is not good at helping the impact of percussion instruments.	If you don't like the percussiveness (e.g., snare), slow down the attack. To increase the ratio of rhythm to melody, shorten (speed up) the attack. Upward expansion is very good at helping the impact of percussion instruments, however, sometimes at the expense of the vocal balance because the percussion becomes more prominent.
	can work very well with upward compression, which fills in any perceived low level "holes" or lost sustain.
Very easy to degrade the liveliness or "bounce" of the music if time constants are not optimized or if overused.	Very easy to enhance the liveliness or "bounce" of the music, but watch out for too much "bounce" or exaggerated dynamics.
tends to go **against** the natural movement of the music, especially when the parameters are not optimized.	tends to work **with** the natural movement of the music, especially when the parameters have been optimized.
tends to de-emphasize musical accents and emphasize the sub accents and sustains in reverse proportion to their original movement.	tends to emphasize the hottest musical accents and to a lesser degree, the sub accents in increased proportion to their original movement.
	Very useful to follow with a limiter, as loud passages are being brought up by the expander. As long as the limiter is used to cheat down very short, momentary transients, it will not significantly diminish the effect of the upward expansion. The limiter's gain reduction meter should be moving very little and on brief occasions, while the expander's gain increase meter should be bouncing with the syllables of the music that's being enhanced. However, if the limiter's gain reduction meter starts to mirror the expander's gain increase meter, then the two processes are canceling each other out and there's too much limiting.
can decrease the overall dynamic range of the song (macrodynamics), in addition to affecting the microdynamic *bounce* of the music.	can increase the overall dynamic range of the song (macrodynamics), making a climax seem even more climactic, which can be very effective.

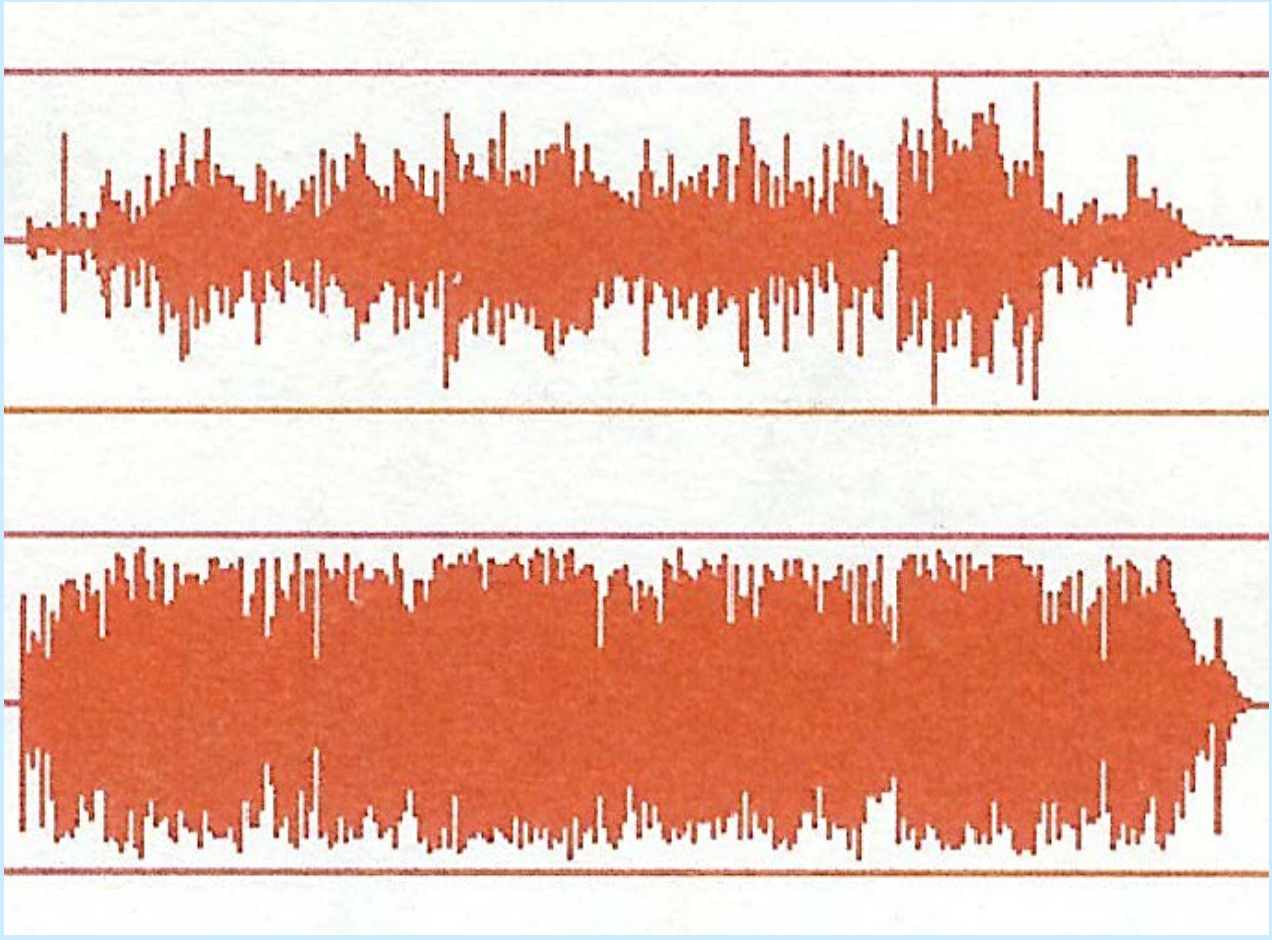
Faders

Temporal faders are used to add “attacks” or “fades” to sections of steady-state sound, or to modify the original characteristics of sound transients.



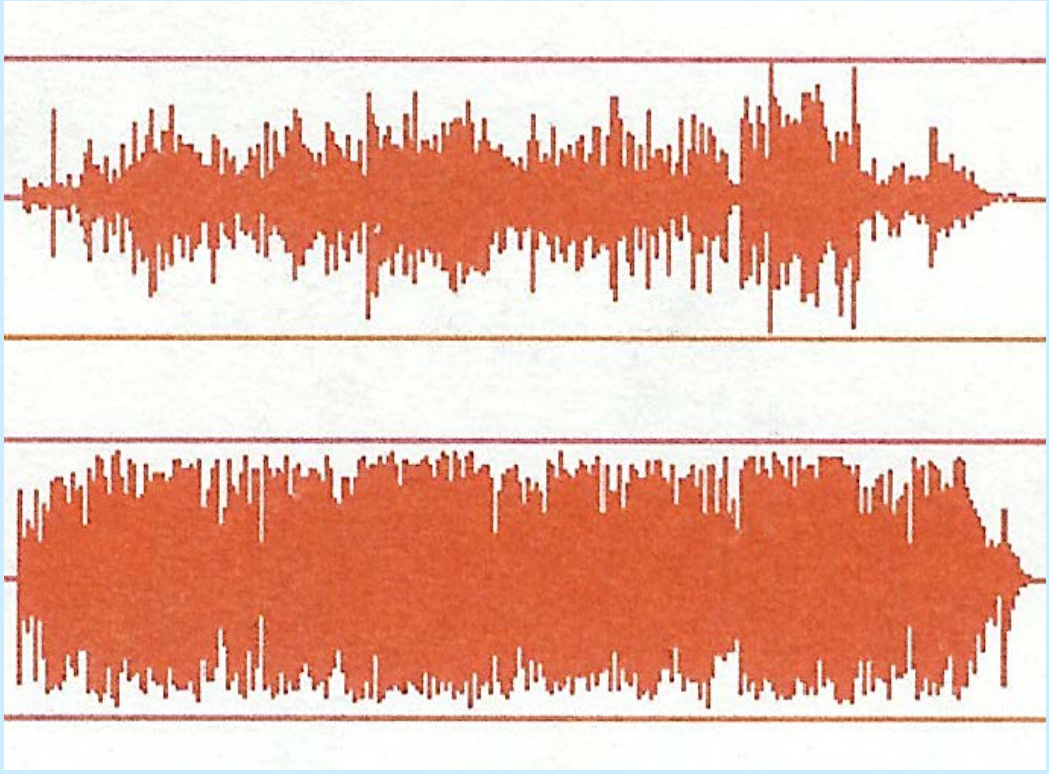
The Final Mastered Result

The final mastered result is often a sound signal which is noticeably different from the original. A particularly obvious example of this are sound masters produced for AM or FM radio broadcast. In the example below, the music signal at the top is the starting mix, while the bottom is the broadcast-ready master.

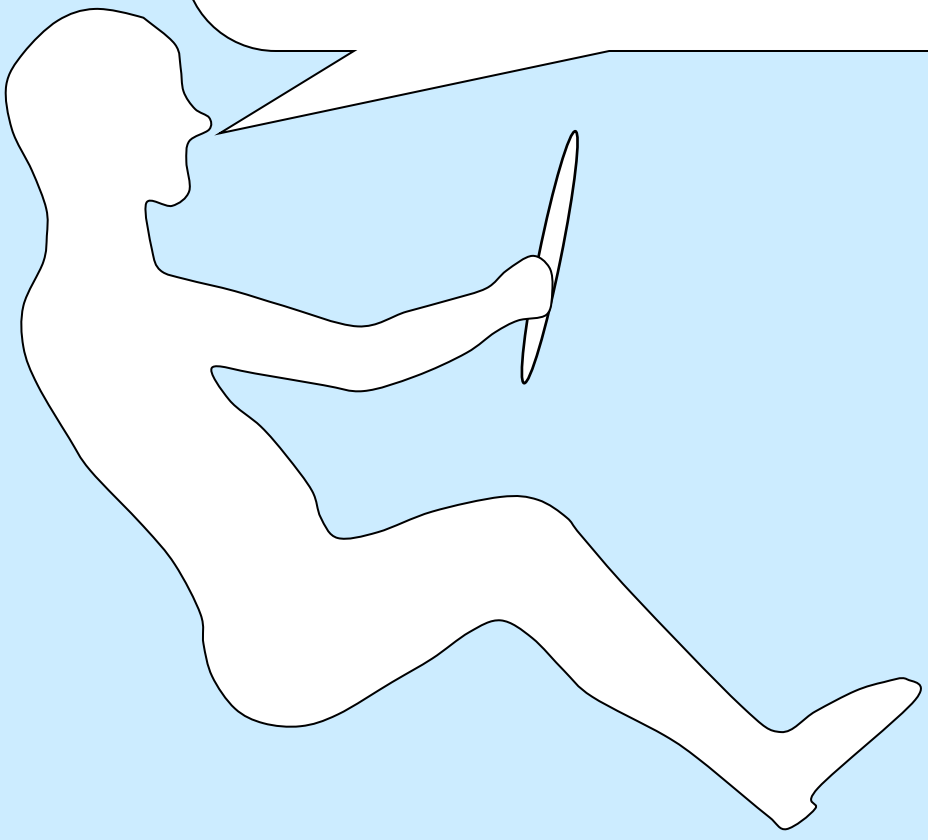


The Final Mastered Result

Compressors and expanders change the statistical properties of a sound signal. Global statistics such as the variance, skewness, kurtosis, r.m.s. or VDV may be changed by more than a factor of 2.0.



Perception Enhancement Principles from Information Theory



What is Information Theory ?

Information theory provides a basis for the analysis of data and situations. Content is described either in terms of the statistical usage patterns of code elements, or by the distinguishing essential characteristics or by the number of choice alternatives.

Information theory evolved due to the need to analyse communication channels such as the telephone. It forms the basis for analysing the efficiency of communication between humans and machines.

Information

A seminal 1948 paper by Shannon defined a measure of the information we get by observing an event which has probability *p* of occurring. If the particular features which describe the event are ignored, the information that can be gained from simply knowing that it occurred can be expressed as

$$I(p) = Log(1/p)$$

Where *I(p)* is the information *p* is the probability.

Information

Defined in this way the information measure I(p) has several properties:

- **The information is a non-negative quantity** $I(p) \geq 0$
- ***If an event has probability 1, we get no information from its occurrence*** $I(1)=0$
- ***It two independent events occur then the information we get from observing both is simply the sum of the individual information values*** $I(p_1,p_2) = I(p_1) + I(p_2)$
- ***The information associated with a particular event is a continuous function of its probability of occurrence***

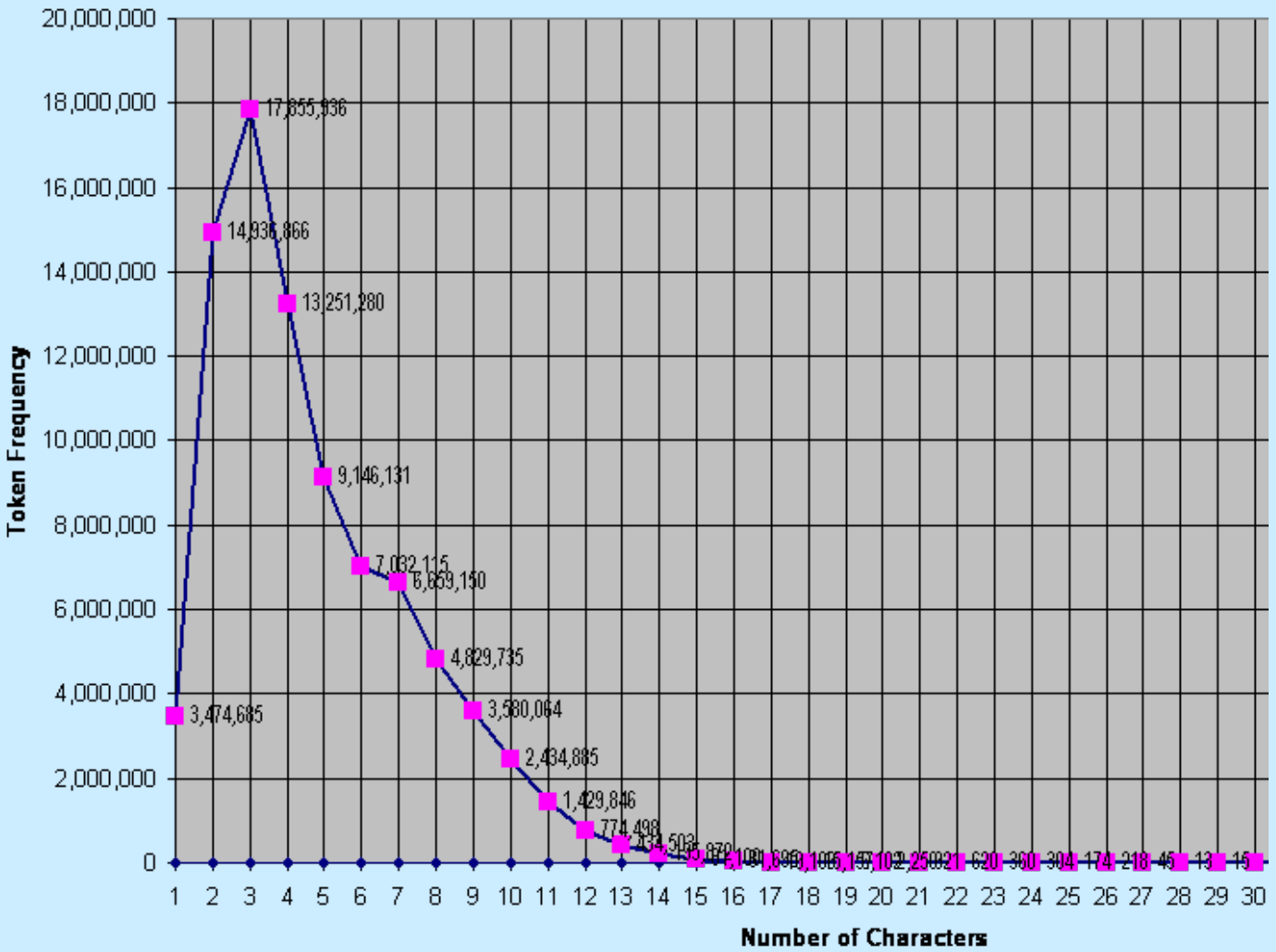
Information

For some transmission containing a set *P* of symbols, the average information obtained is determined by summing across all symbols. This average information is also known as the information entropy *H(P)* .

$$H(P) = < I(p) > = \sum_{i=1}^{n} p_i \, Log\,(1/\, p_i)$$

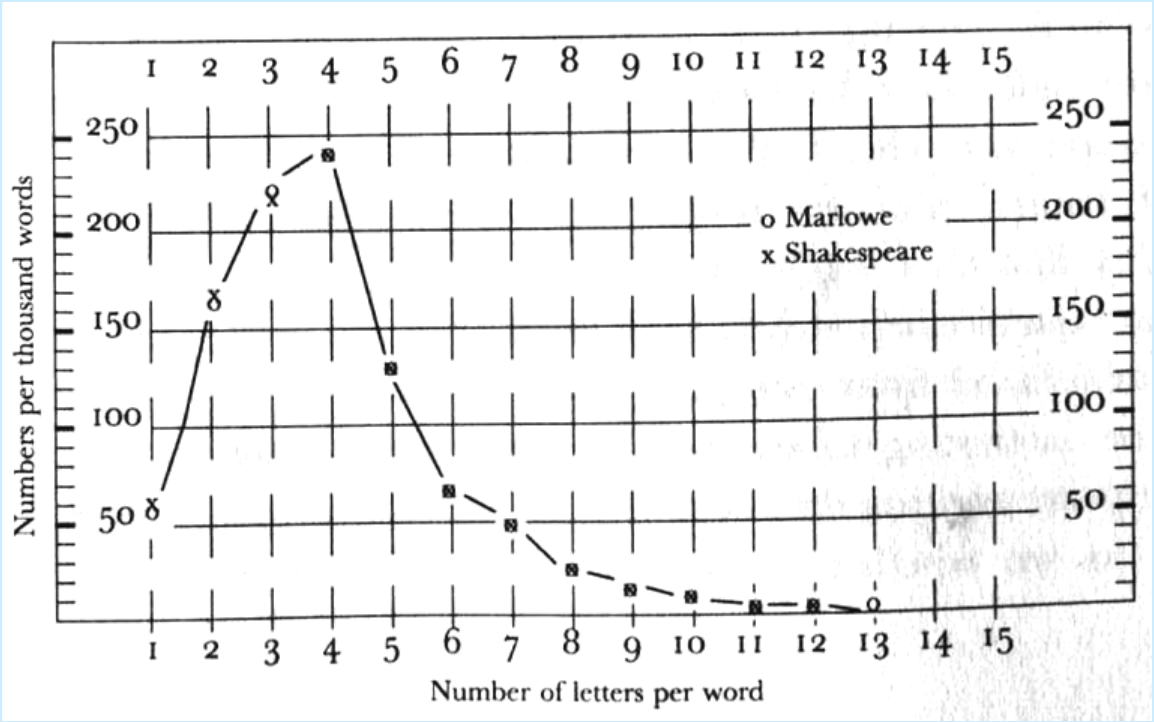
Information Content of Language

One common application of information theory has been the analysis of language. Word frequency lists and their inverse, word probability lists, have been compiled for many languages. The example below is a word length frequency list from the British National Corpus (BNC) database.



Information Content of Language

A well known linguistic application has been the writings of William Shakespeare. Various researchers have used word frequency, word probability or information entropy to support their hypothesis regarding the actual author of certain works which have traditionally been attributed to Shakespeare.

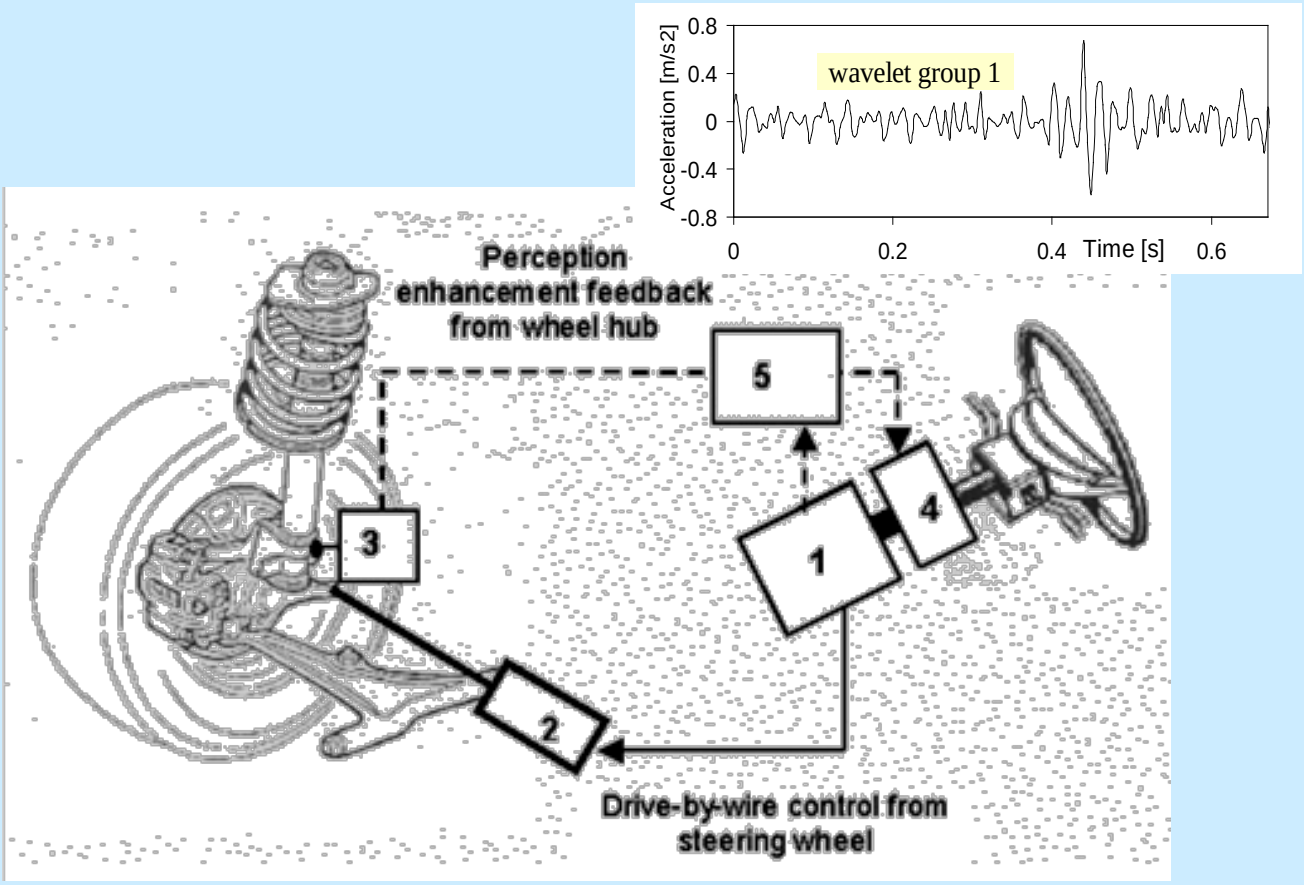


Information Content of Language

Many empirical calculations have been made over the years to estimate the information entropy of the English language. Most studies suggest an entropy per word of about 12 bits and an entropy per single character of about 1.5 bits. Values can differ slightly depending on the language corpus being evaluated. More limited vocabularies (such as computer menu systems) are characterised by higher entropy values.

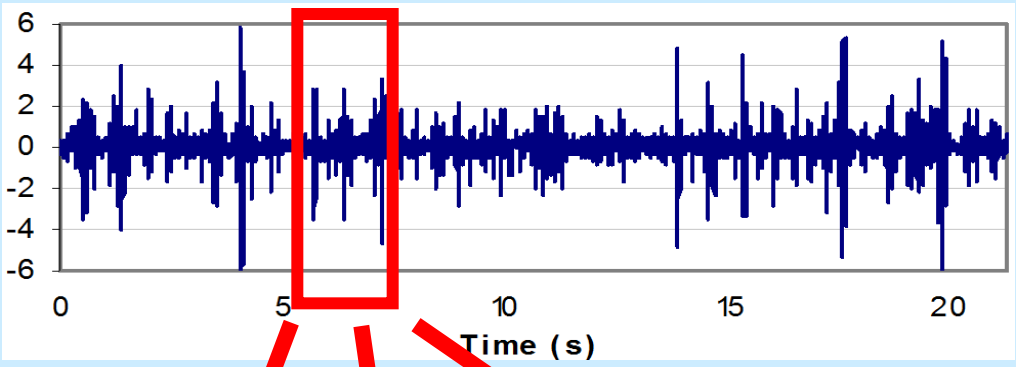
Perception Enhancement Systems

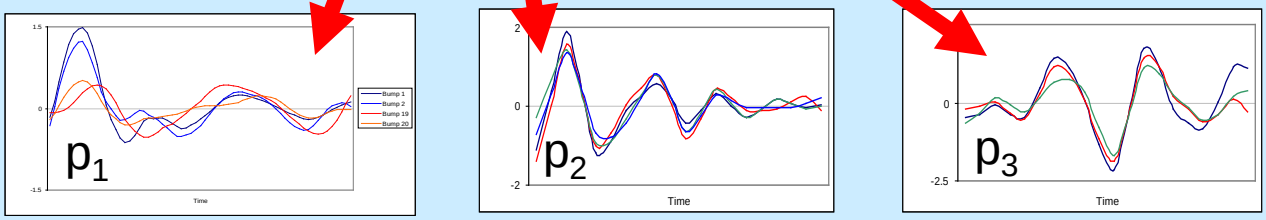
The term *Perception Enhancement System* can be used to describe any device which optimises the feedback of vehicle and environmental data. Such systems can be based on an information theoretic point of view, and can make the vehicle feel like an extension of the driver.



Research is attempting to define the frequency bands containing the vehicle dynamic state information, the minimum and maximum signal scaling which humans can interpret, and a library of common road features.

Perception Enhancement Systems

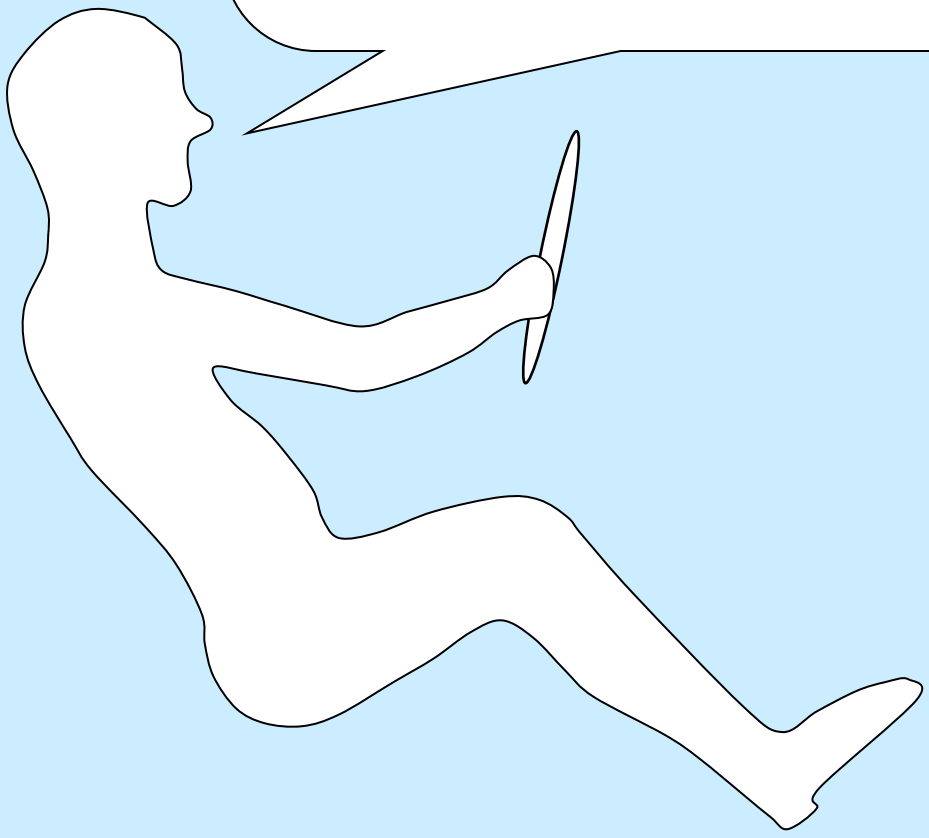




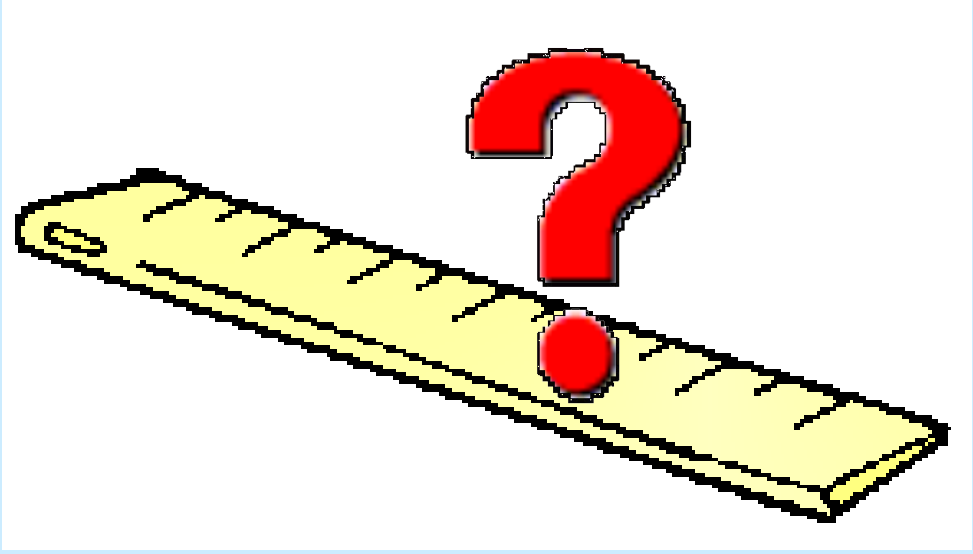
$$H = -\sum_{i=1}^{n} p_i \log_2 p_i \quad bits\ per\ symbol$$

A possible basis for a vehicular steering PES is an *Information Entropy* measure which is used in conjunction with a library of road features.

Experiments in Road Surface Detection



Research Aims



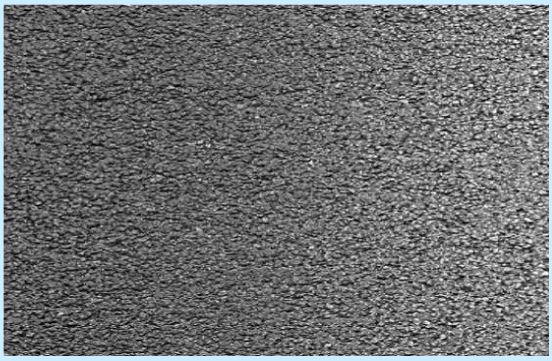
The objectives were:

- **To investigate the human ability to identify road surfaces based on the tactile stimuli (vibration) of the steering wheel.**

- **To determine, based on the human responses, if different road surfaces require different perception enhancement strategies.**

Test Roads

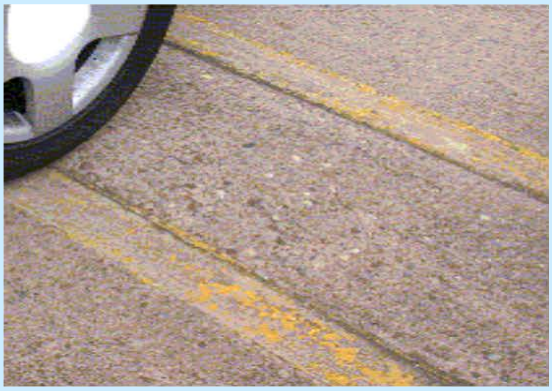
Tarmac road (vehicle speed : 96kph)



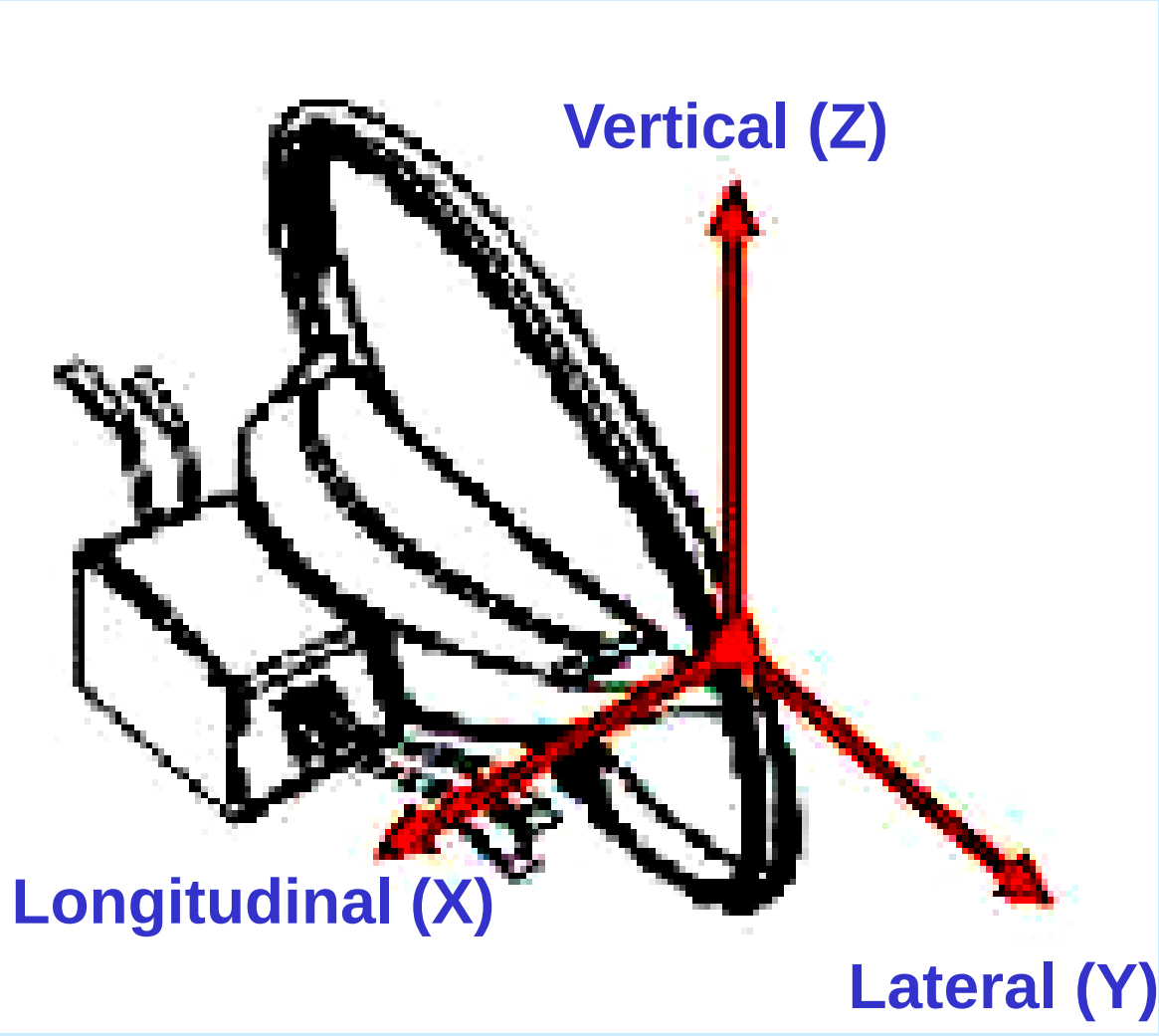
Cobblestones road (vehicle speed : 30kph)

Concrete road (vehicle speed : 96kph)

Bump road (vehicle speed : 50kph)

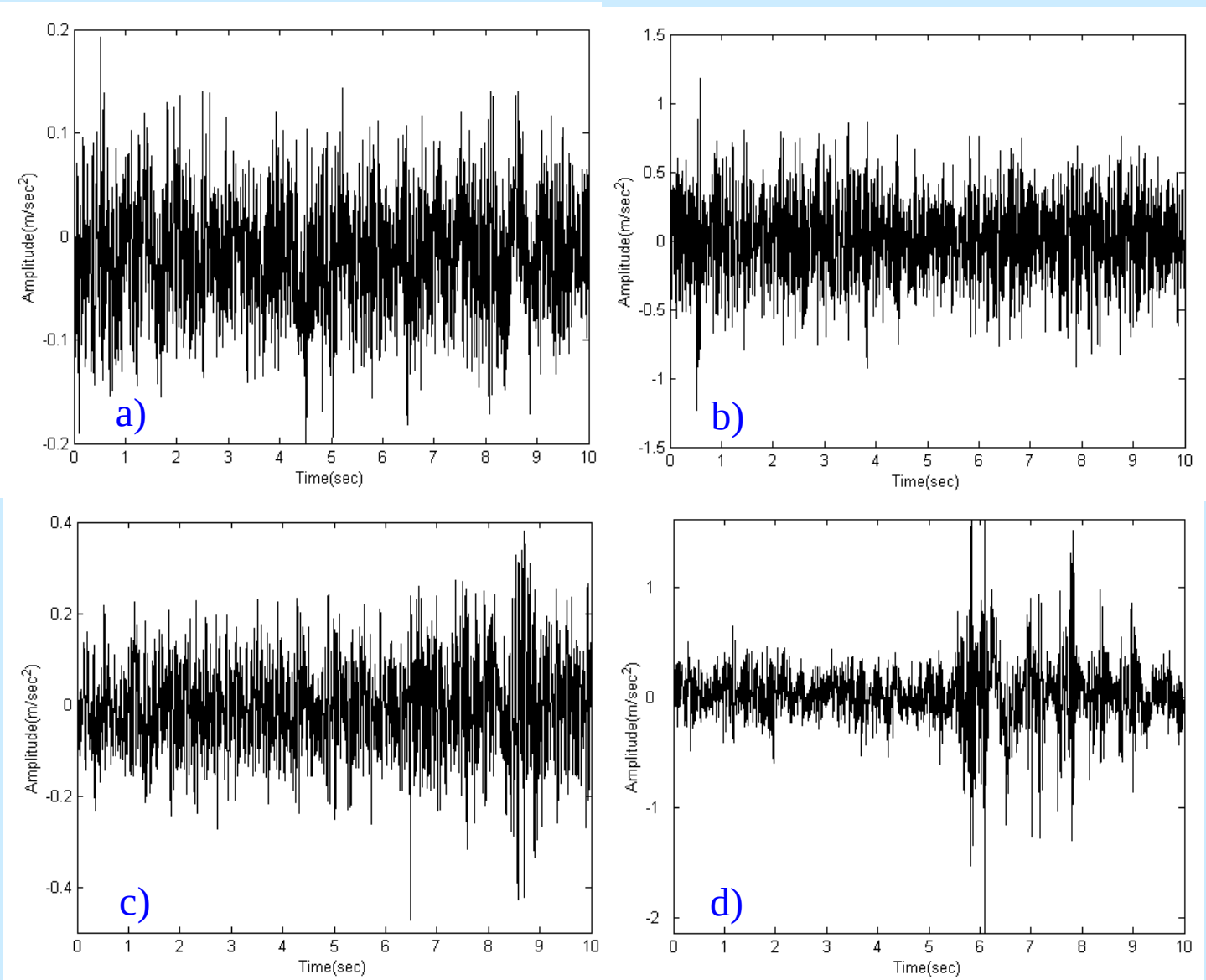


Steering Vibration



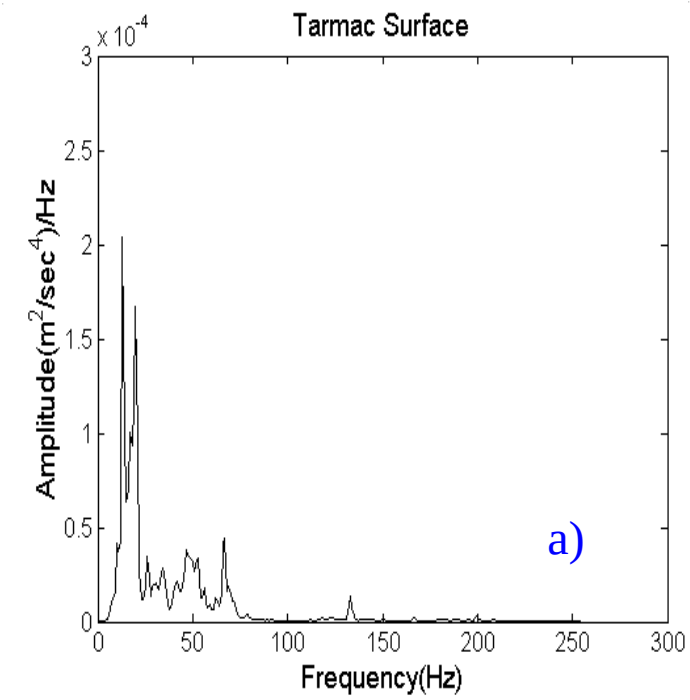
Measurements of steering wheel acceleration were made using a triaxial accelerometer attached to a mounting block. The tangential acceleration (Z direction) was chosen for use in the laboratory experiments.

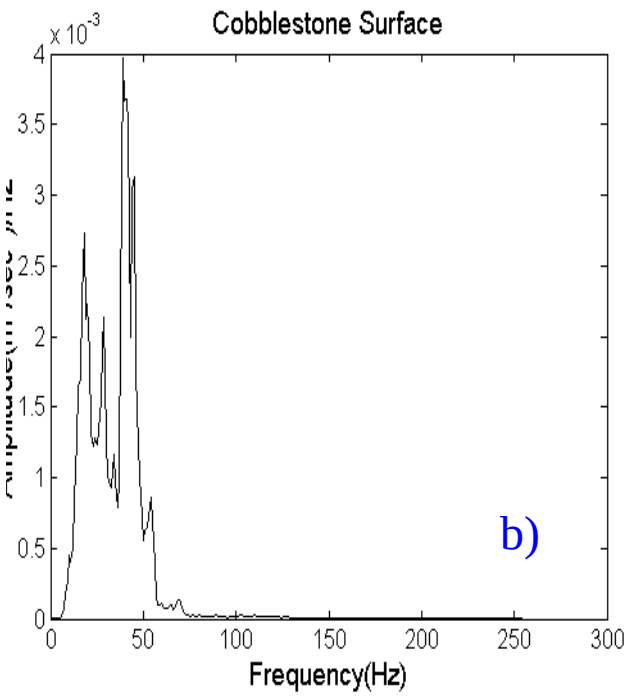
Steering Vibration

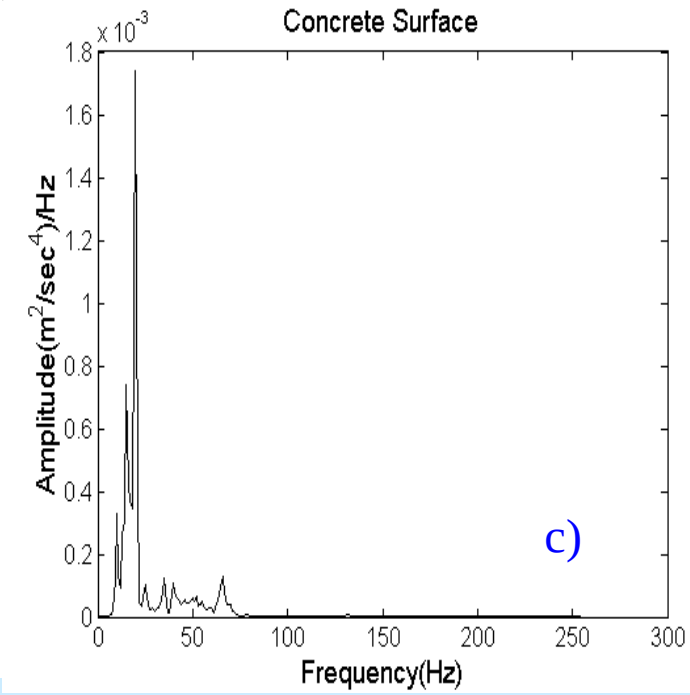


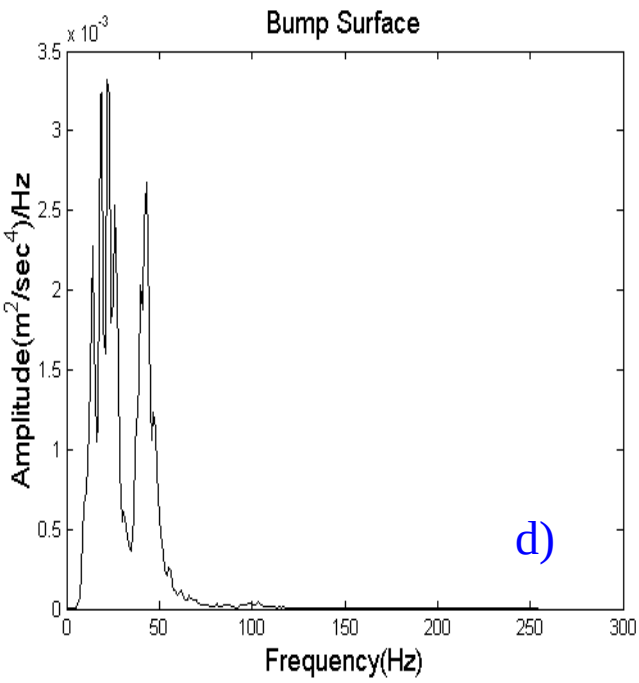
a) Tarmac road surface (vehicle speed: 96 km/h)
b) Cobblestone road surface (vehicle speed: 30 km/h)
c) Concrete road surface (vehicle speed: 96 km/h)
d) Bump road surface (vehicle speed: 50 km/h)

Steering Vibration



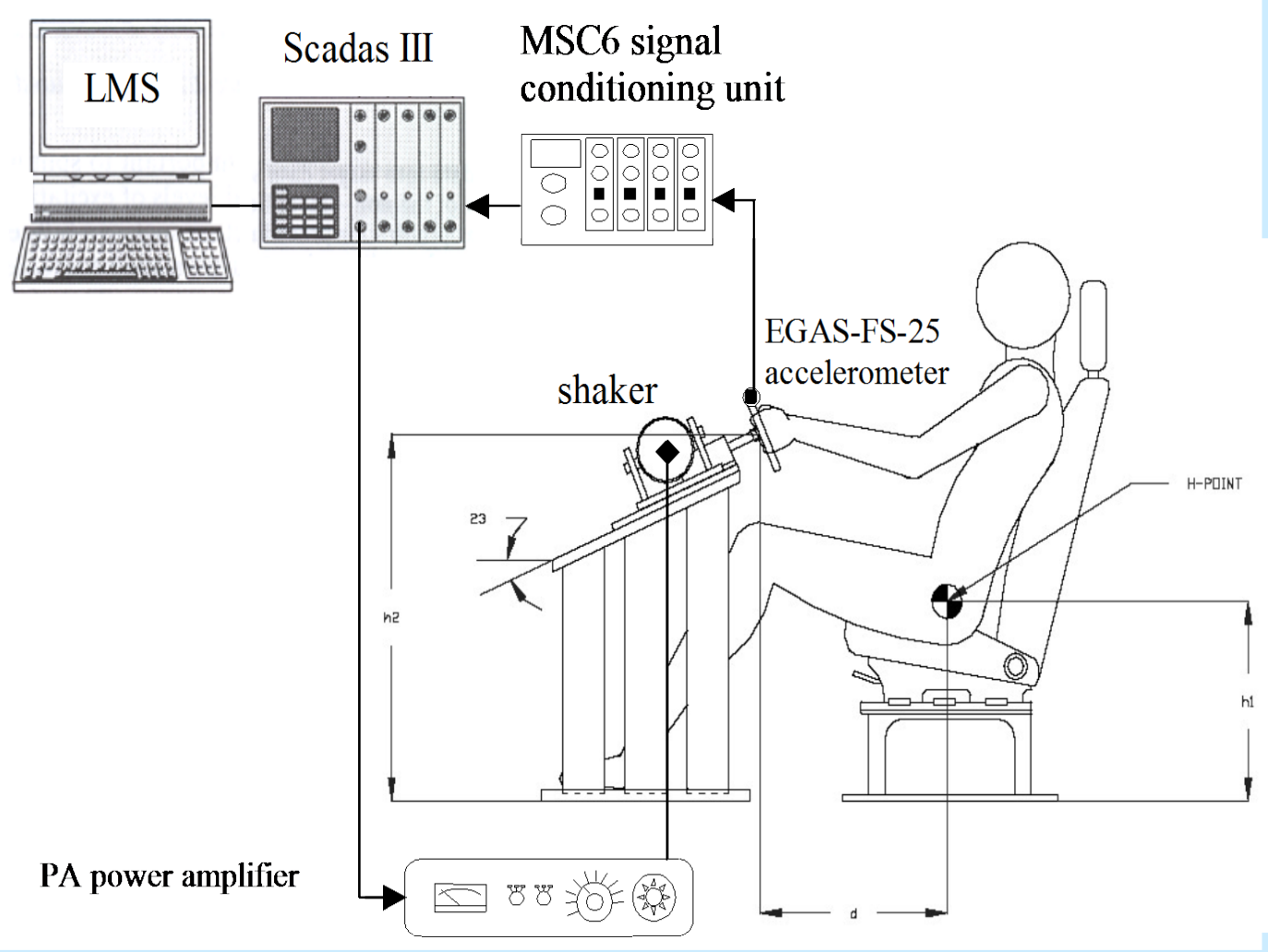






a) Tarmac road surface (vehicle speed: 96 km/h)
b) Cobblestone road surface (vehicle speed: 30 km/h)
c) Concrete road surface (vehicle speed: 96 km/h)
d) Bump road surface (vehicle speed: 50 km/h)

Steering Vibration Test Facility



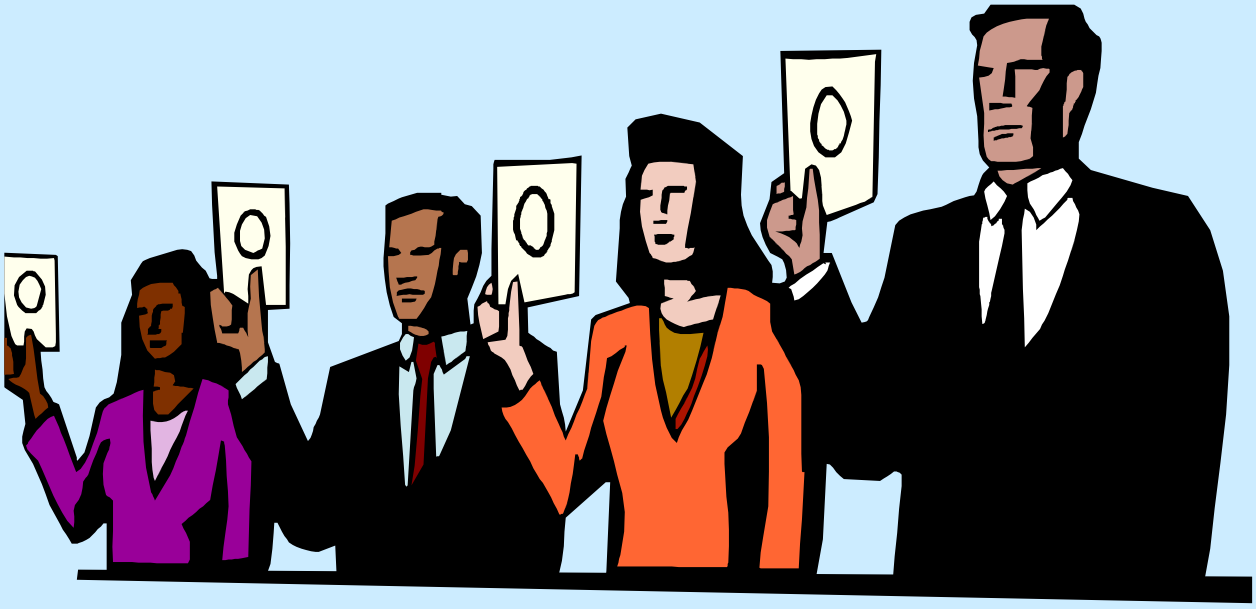
Geometric Parameter	Value
Seat H point height from floor, h_1	275 mm
Horizontal distance adjustable from H point to steering wheel hub centre, d	390-550 mm
Steering wheel hub centre height above floor, h_2	710 mm
Steering column angle with respect to floor	23 º
Steering wheel handle diameter	12.5 mm
Steering wheel diameter	325 mm

Detectability Tests

A large photograph was shown which was similar to the view which would be seen through the front window of the automobile.

For each stimuli, the subject was asked to indicate whether the stimuli was, or was not, from the road of the photograph.

Test Participants

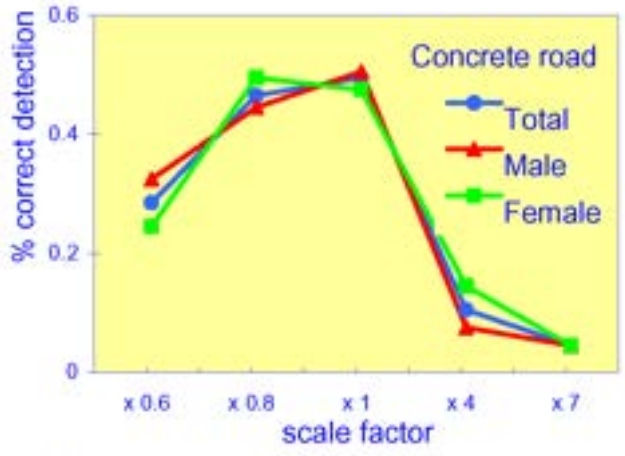


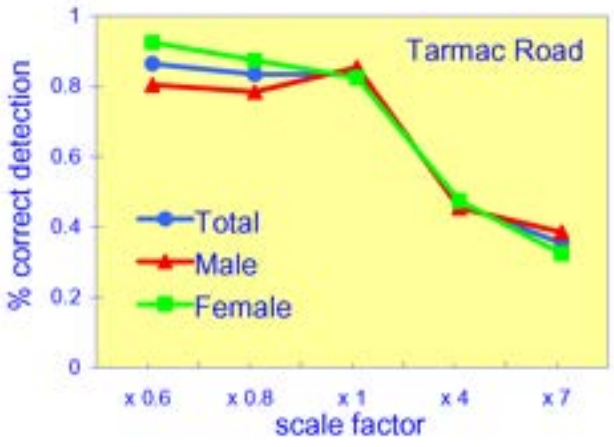
Each test involved a group of university staff and students who acted as subjects.

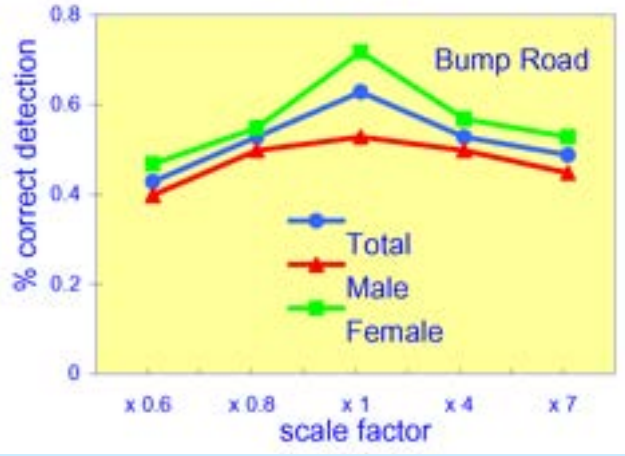
The age, height and mass of each participant was recorded so as to monitor that the physical characteristics of each test group were close to the 50 percentile values for the UK population.

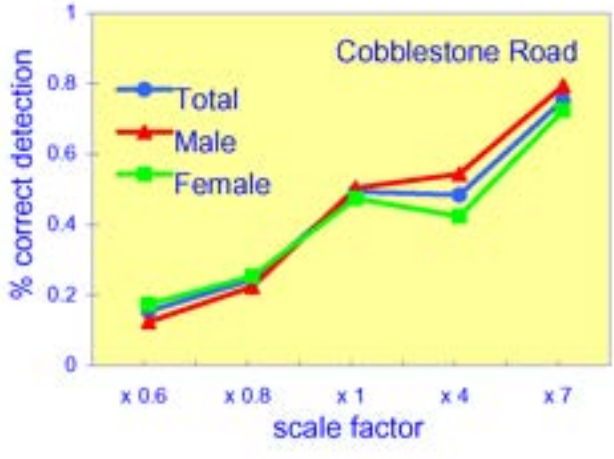
Each participant was also asked to state if he or she suffered any medical condition which might effect the perception of vibration or sound. Also, factors which are known to effect the human perception of vibration and sound such as smoking or drinking coffee were also recorded.

Effect of Scale/Gain Change



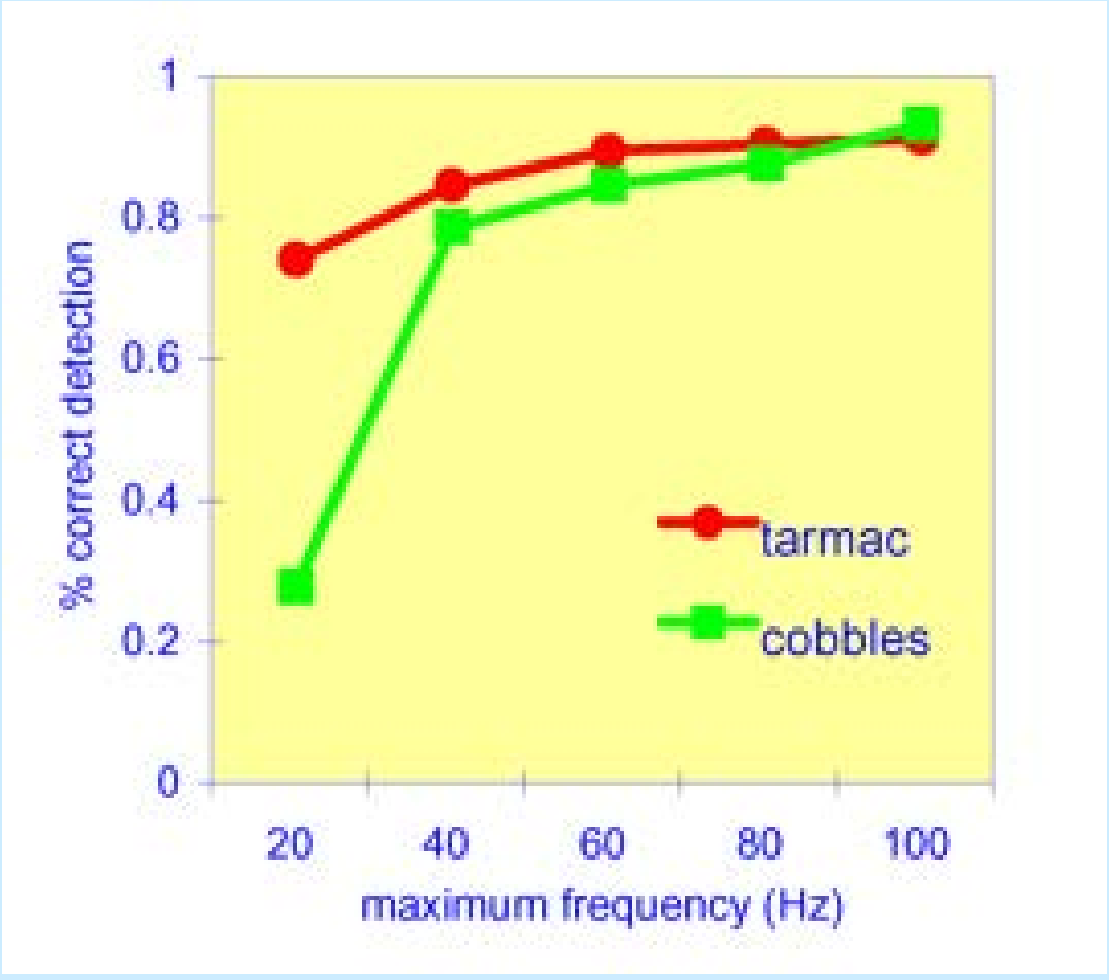






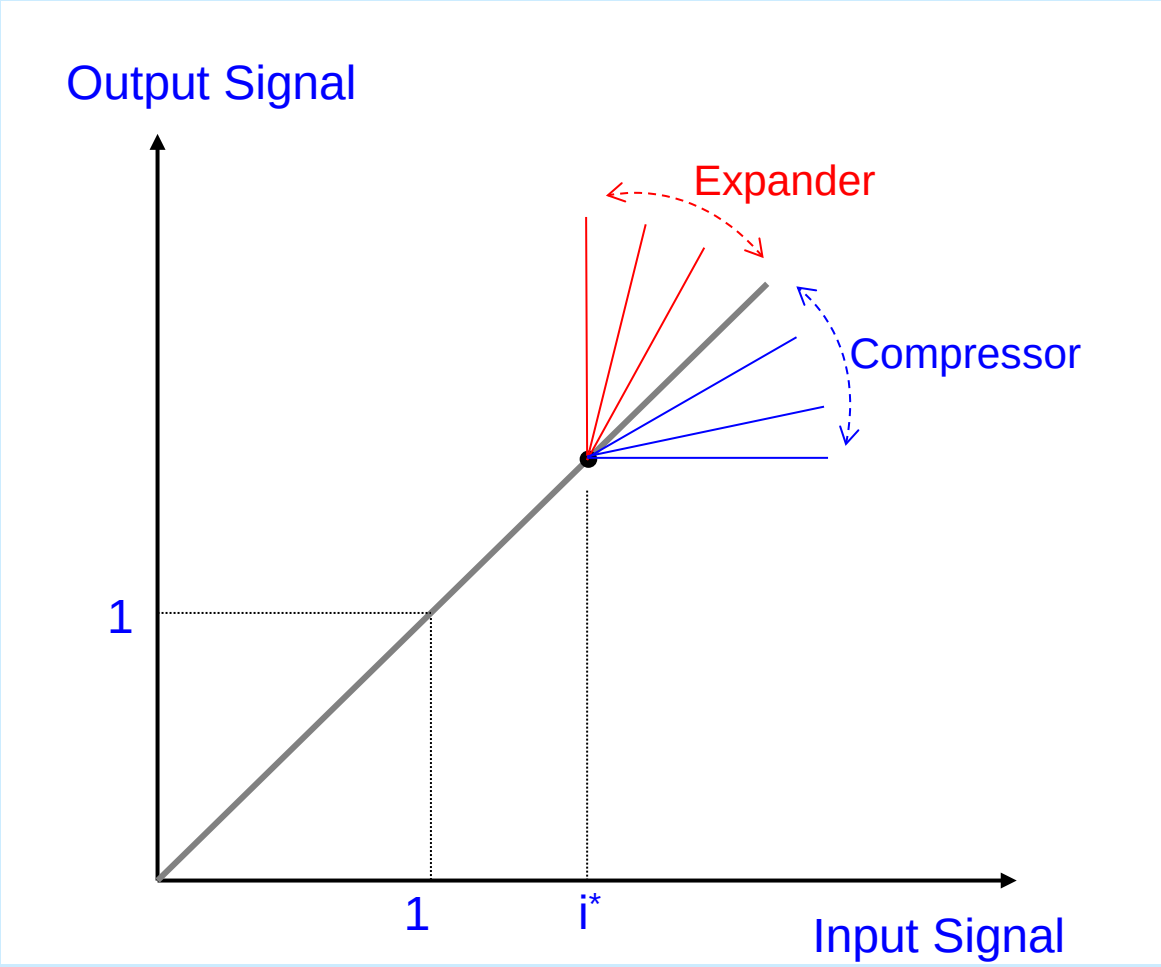
Three distinct detectability behaviors are found in the results (40 test subjects).

Effect of Frequency Bandwidth Change



Detection improves monotonically with bandwidth, achieving maximal detectability by about 80 to 90 Hz (40 test subjects).

Effect of Signal Compression or Expansion

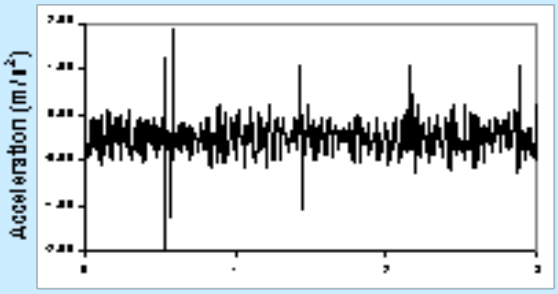


Steering vibration stimuli were modified by either compressing or expanding all the data points whose amplitudes were greater than a critical value I*.

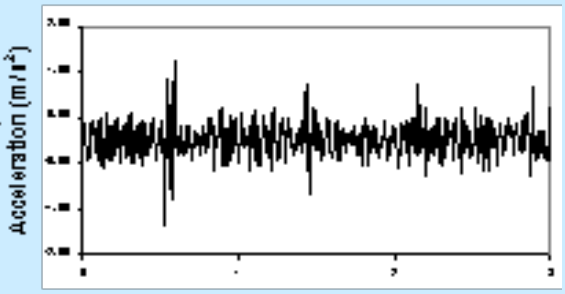
Effect of Signal Compression or Expansion

The examples on the right show the effect of various compression or expansion values when the critical amplitude is taken to be the three standard deviation value of the data points composing the steering acceleration time history.

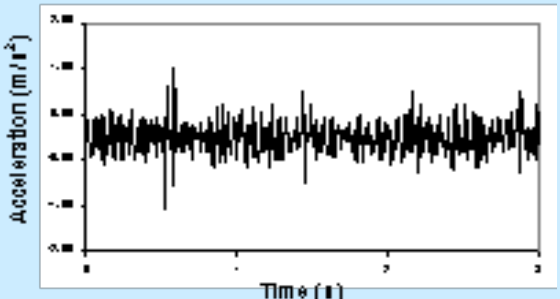
EXPANDER 2.0



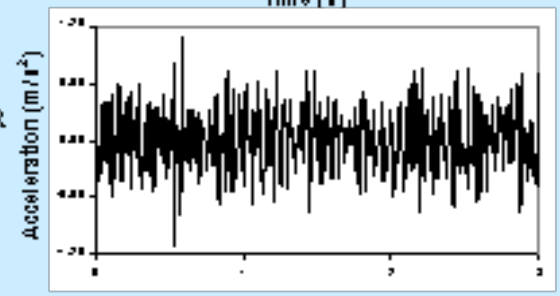
EXPANDER 1.5



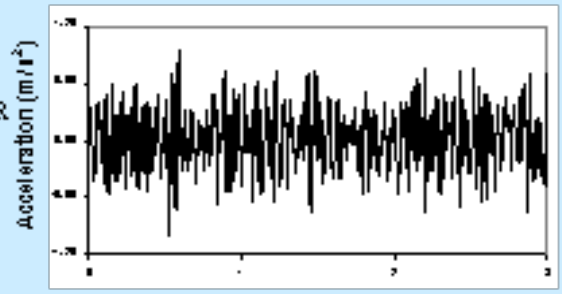
EXPANDER 1.25



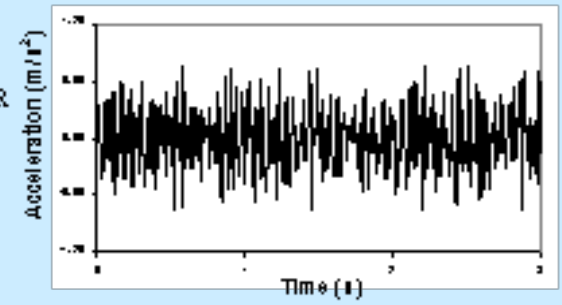
COMPRESSOR 0.9



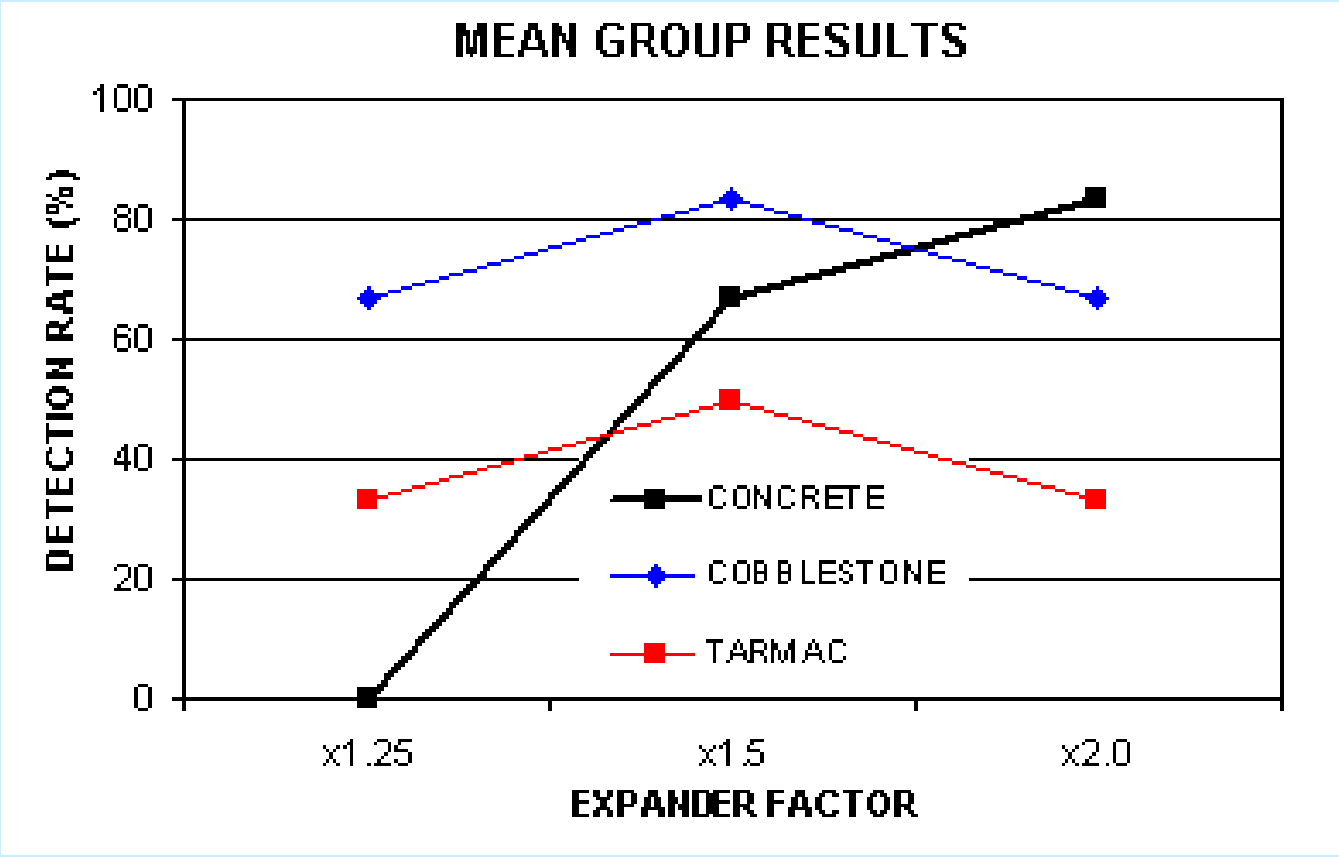
COMPRESSOR 0.8



COMPRESSOR 0.6

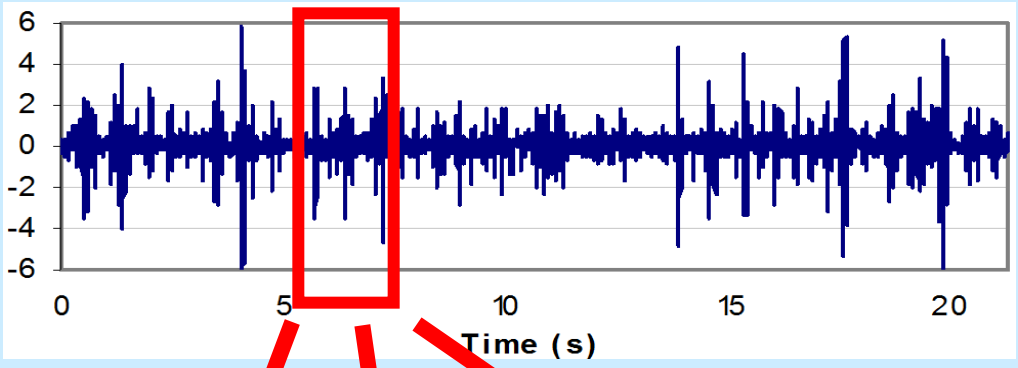


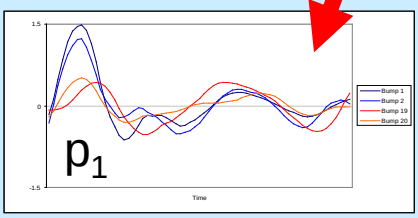
Effect of Signal Compression or Expansion

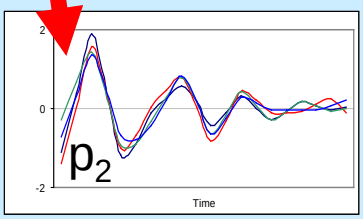


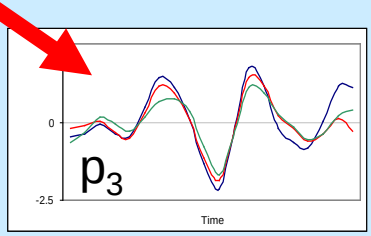
Signal expansion was found to produce beneficial effects for the smoothest road surface (concrete). The improvement, due to the increased amplitudes of only the highest peaks, is in contrast to the results from scale/gain change (20 subjects).

Effect of Scaling on Individual Bumps



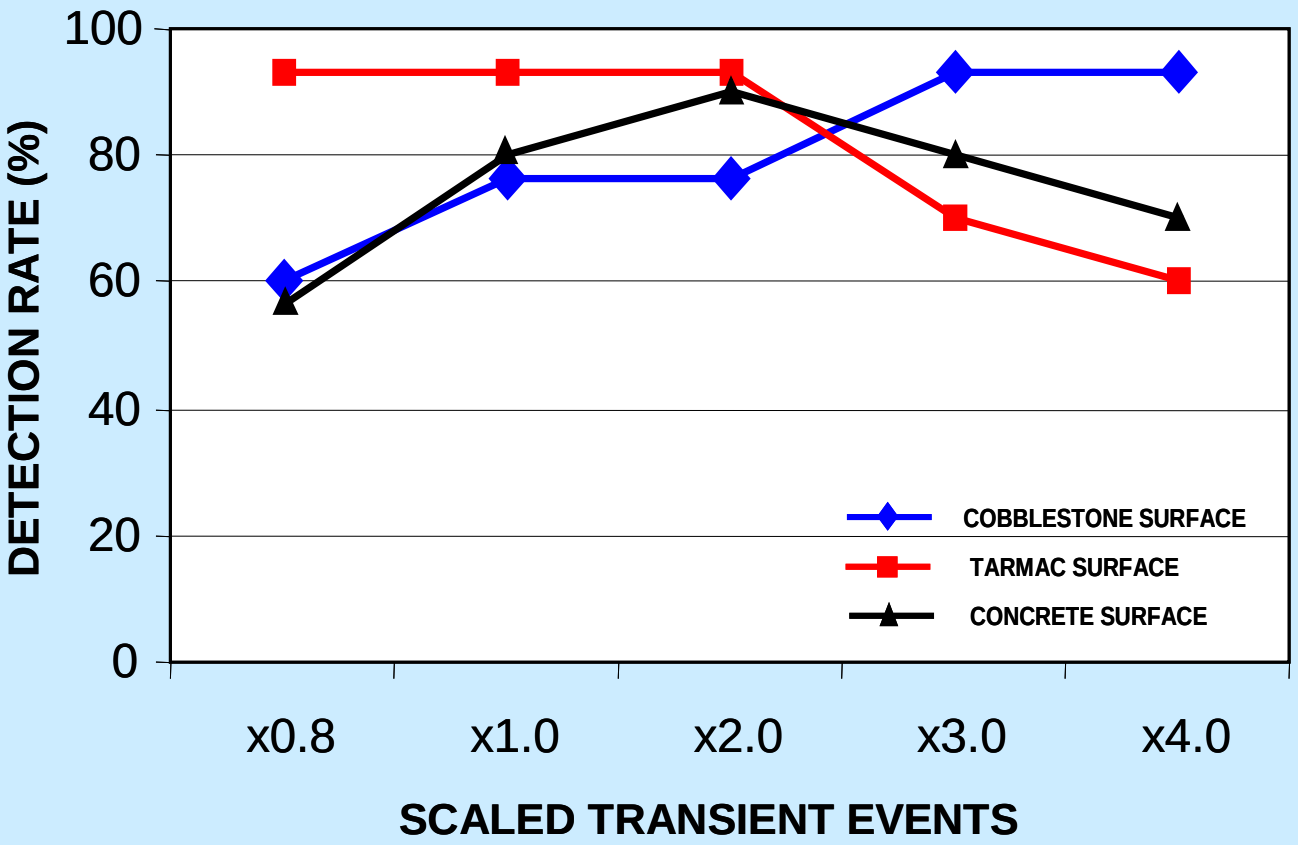






One area of research is the role played by high amplitude vibrational transients. These “bump” features are important because the human nervous system pays great attention to high amplitude events, as evidenced by fourth power evaluation methods such as the vibration dose value (VDV).

Effect of Scaling on Individual Bumps



Scaling of the individual bumps was found to be beneficial for two of the road surfaces. For the smoothest road surface (concrete) the improvement was optimal at a scale factor of 2.0 (15 subjects).

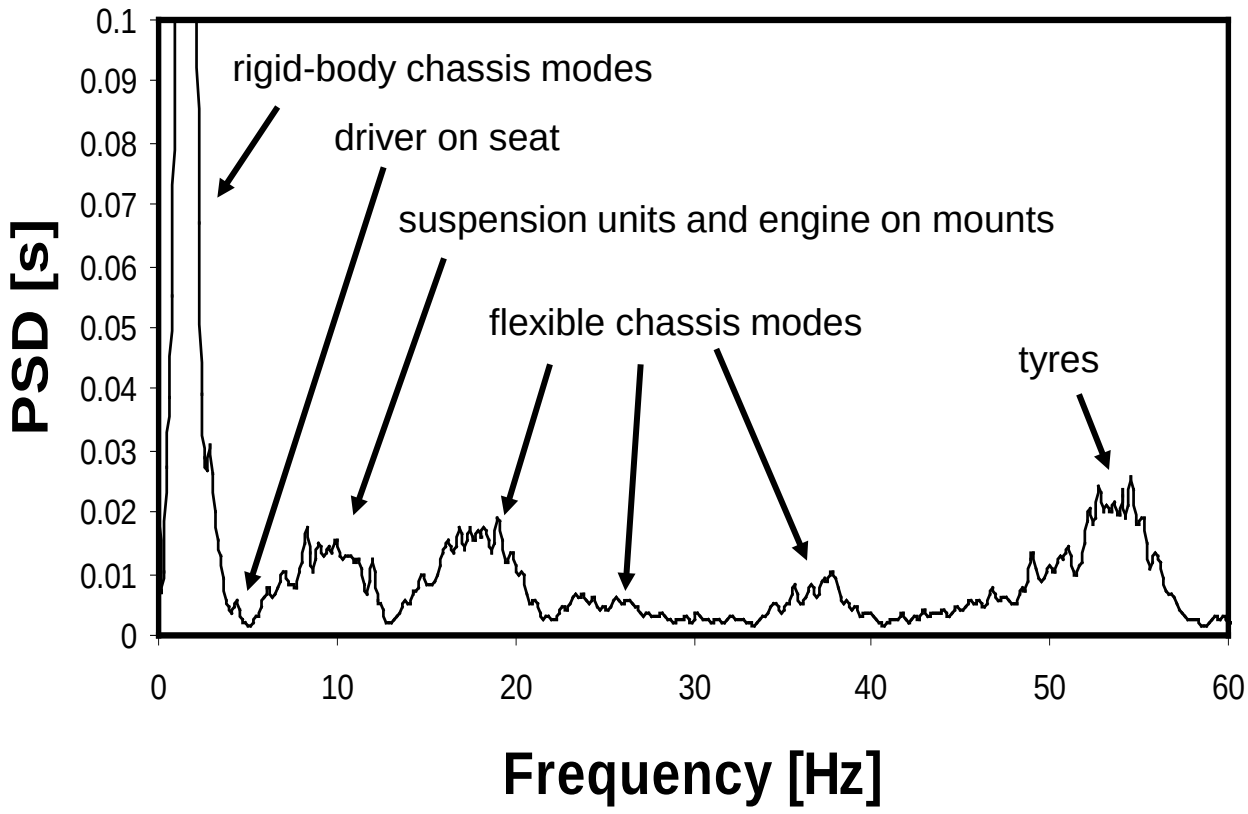
Detectability Results

The behavior of the test data suggests:

- A fixed gain for enhancing the perception of steering wheel vibration stimuli is not appropriate for all road surfaces.
- A bandwidth of at least 80 Hz is required for automotive steering systems (either traditional electrical or drive-by-wire) in order to guarantee road surface detection.
- Stimuli expansion appears to produce a beneficial effect towards enhancing the perception of low intensity stimuli from smooth surfaces such as the concrete road.
- Selective scaling of individual bump features appears to produce a beneficial effect towards enhancing the perception of low intensity stimuli from smooth surfaces such as the concrete road.

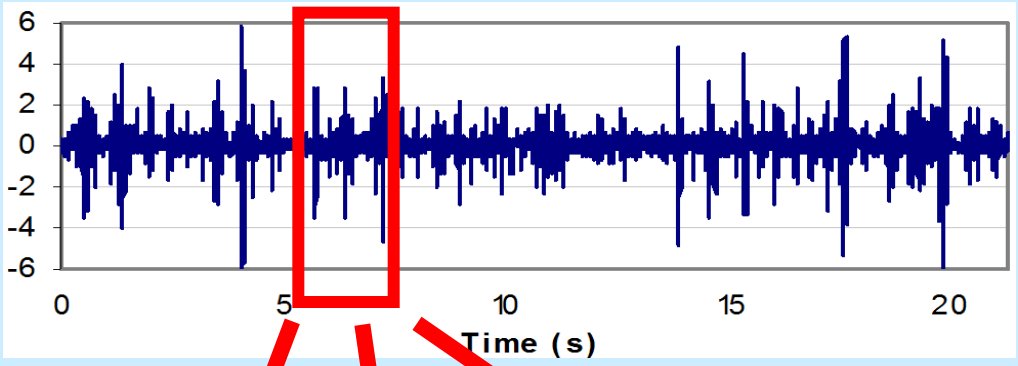

Continuing
Research

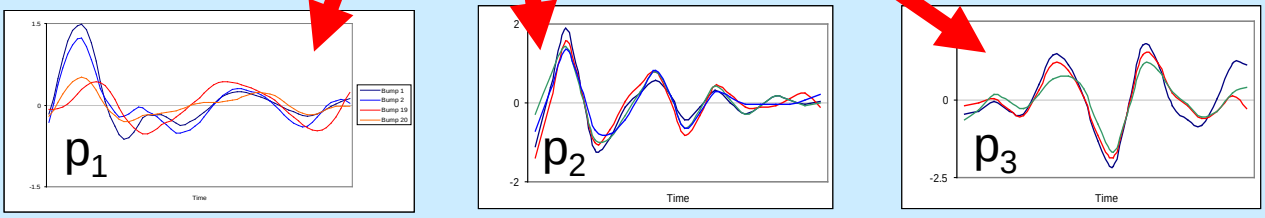
Continuing Research



From a perception enhancement point of view, the resonance behaviours of the vehicle subsystems should be considered as sources of information about the dynamic state of the vehicle. Perception enhancement thus suggests that several of these vibrations should not be reduced by more than a minimum. The example above is a vertical seat guide acceleration signal measured at the seat rail mounting bolt in a Renault automobile.

Continuing Research

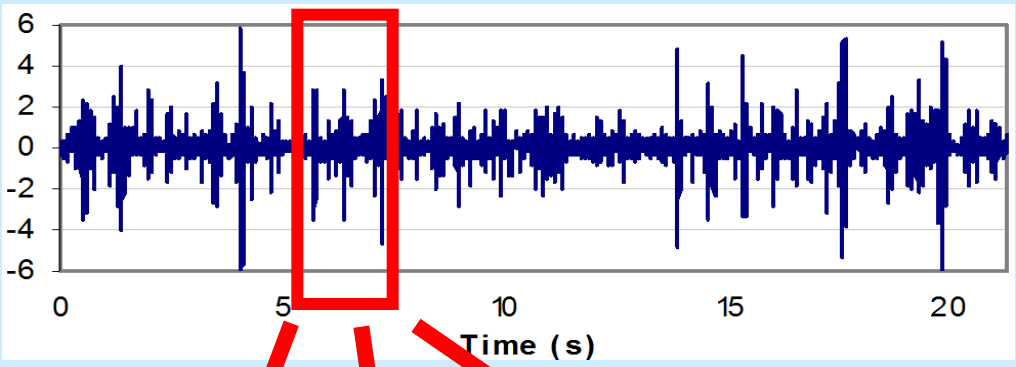


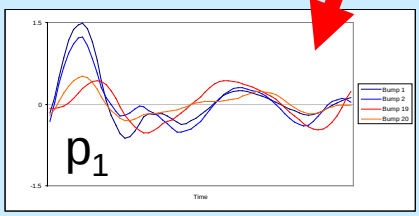


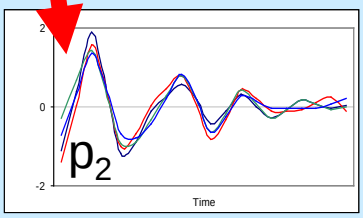
Bump selection and modification

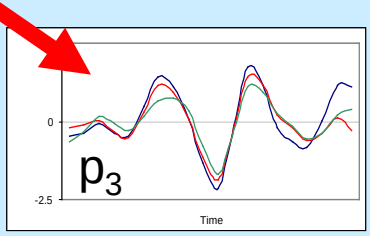
The *Mildly Nonstationary Mission Synthesis (MNMS)* algorithm is being used as a “bump” selecting mechanism and a “bump” modifying mechanism, which constitutes a perception enhancement controller.

Continuing Research









$$H = -\sum_{i=1}^{n} p_i \log_2 p_i \quad bits\ per\ symbol$$

One working hypothesis is that different driving conditions are characterised by different mean entropies. Source entropy could then be used to classify the driving situation, and to decide the best mix of “bumps” to send to the driver to inform him or her about the dynamic state of the vehicle.

Continuing Research

An expected future application of perception enhancement is in the area of vehicle active safety associated with adherence loss. Perception enhancement can facilitate the driver's task of identifying an upcoming loss of adherence. Further, the perception enhancing controller can induce "virtual slides" to warn the driver of danger.