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The salience of fire alarm signals for sleeping individuals: A novel approach to signal design

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Contrary to popular belief, the human brain remains in a very active state during sleep,[1] and being asleep is by no means equal to an absence of conscious experience.[2] Previous research has shown that participants can produce a behavioural response to auditory stimuli during sleep without necessarily awakening.[3] Such responses are elicited more readily during the subjectively lighter stages of sleep compared to the subjectively deeper stages. This is illustrated when we consider that auditory arousal thresholds (AAT's) normally progressively decline across the night,[4] which is commensurate with the declining proportion of time spent in deep sleep as sleep progresses.[5]

Although the previously cited results describe the norm for many, it is problematic for the designers of alarm signals that AAT research has revealed that there are important individual differences that are likely to affect whether a sleeping person will respond to an auditory signal. These differences are as follows:

- Sleepy individuals (defined as sleep latency ≤ 5 minutes), and alert individuals (defined as sleep latency ≥ 10 minutes) who have been deprived of sleep, do not show the usual decline in AAT's across the night.[6]
- Sleep deprived young adults will not reliably awaken to an alarm signal, regardless of sleep stage.[7]
- Six to seventeen year old children will not reliably awaken to an alarm signal.[8, 9]
- Both the frequency of awakenings, and the intensity of a stimulus required to induce awakening, is related to age, with more frequent awakenings in response to lower stimulus intensity as age increases.[10]
- Individual differences account for more variability in AAT's than sleep stage or age.[11]

Added to the results indicating that individual differences affect likelihood of awakening are the results showing the importance of the salience of the auditory stimuli used.[12, 13] From this research it has been concluded that cortical analysis of the meaningfulness of auditory stimuli precedes arousal. Subsequent research has provided ample supporting evidence in that the increased significance of auditory stimuli has been found to lower AAT's, regardless of sleep stage,[14] and to increase the overall probability of a response.[15] Most particularly it has been concluded that the sleeping brain effectively processes the emotional content of auditory stimuli.

Research using functional MRI technology has confirmed that sounds with an affective significance lead to lower AAT's and increase the probability of a response.[16] It was found that *during sleep only*, presentation of a participant's name showed activation in the left amygdala and left prefrontal cortex. Since the role of the amygdala is well established in the processing of emotion,[17] it was concluded that the amygdala may process the affective significance of a participant's name and activate the prefrontal cortex to induce arousal. This is supported by neuropsychological research which has found that the amygdala can process emotional information directly, without cortical input. Most particularly a "pathway of learned fear" has been proposed which implicates the amygdala in the production of a physiological response to affective stimuli.

The emotional significance of signals would seem to be a very important consideration in the modern world where our lives are inundated with an assortment of beeps, bleeps and buzzes designed to remind us of an array of things that vary greatly in importance, for example the ring of a mobile telephone, the electronic alarm clock, the sound of a truck backing up, or the timer on a cooker. A direct consequence of our noisy lives seems to be that the salience of a beeping alarm signal has greatly decreased to the extent that many have become capable of ignoring such sounds.[11] The message of urgency has, to a certain extent, been lost.

A similar problem emerges when we consider signal recognisability. Recent research has found that few people are likely to identify the Temporal Three Evacuation Signal, which follows the requirements of International Standard 8201 for audible emergency evacuation signals, as a smoke alarm.[18] These findings suggest that research is required to address the problem of alarm signal salience from a different and novel perspective.

A different approach to signal design can be taken by returning to the basics of human perception and information processing. In 1979, psychologist James Gibson[19] put forward a theory of perceptual affordances which stated that the way humans perceive an object is determined by our own experience. He proposed that our perception is based upon our interpretation of what is being looked at (e.g. it can be climbed, sat on, used for shelter, etc.) rather than the purely physical aspects of what is seen (e.g., the size, colour, or shape). According to Gibsonian theory perception is enhanced if a stimulus is naturalistic and conveys meaning directly, with a minimum of interpretation. Innovative research has drawn from Gibson's theory of affordances to develop alarms with sounds that closely matched the emergency situations within a hospital intensive care ward.[20] It was found that naturalistic alarm signals were more effective than the current beeping signals in alerting novice medical staff who were not trained using the current sounds.

An extensive body of research exists in the field of ergonomics which explores the way humans react to different auditory alarm signals for industrial applications. One alternative approach taken in this field has been to consider the use of a human voice for warning signals. Human voice alarms have distinctive appeal in that they can convey direct meaning, and can also directly convey emotional significance. The research has found the following:

- Individuals can successfully identify the emotion being conveyed when actors deliver signal words or phrases.[21]
- The way in which signal words are spoken determines the believability, appropriateness, and most importantly, sense of urgency being conveyed.[22]
- An increase in pitch of voice is equated with an increase in the perceived intensity of the emotion being conveyed, whether this emotion is positive or negative.[23]
- Human voice alarms are perceived as more urgent[24] and intelligible[25] than computer synthesized voice alarms, even when the computer generated sound has been manipulated to convey urgency.[24]
- The female voice is perceived as more urgent than the male voice.[26, 24]
- The level of urgency perceived varies for different signal words with 'deadly' and 'danger' perceived as most urgent, followed by 'warning', 'caution', and 'note'.[24, 27]

Both novel approaches, a *naturalistic* sound and an *urgent* voice signal, might then be expected to stimulate an emotional cognitive response, which should facilitate arousal as described above. It was therefore hypothesized that a more meaningful, perhaps even emotional, signal would decrease the required arousal threshold and therefore be more successful in waking those people currently at risk of not responding.

A pilot study with two distinct phases was conducted with the aim of selecting a single new alarm signal that would be tested against other established signals in subsequent studies (See Ball & Bruck, this publication). The challenge was to design a meaningful signal that would awaken sleeping individuals most easily, that is at the lowest possible volume.

PHASE ONE – Signal Selection

The purpose of the first phase was to select three new alarm signals that were distinctly different from the current beeping signals used around the world. The questions were designed to elicit a range of responses based upon the previously presented research concerning the success of stimuli with an emotional significance, and the necessity that a person will be awakened, and then respond to the signal.

METHOD

Participants

Information was gathered from 163 individuals who were staff and students of Victoria University in Melbourne, Australia. Details were not formally collected regarding the age and sex of participants, however it is estimated that ages ranged from 17 to 65 years, and that approximately ¾ were female. In most cases participants provided multiple responses to the questions posed.

Materials

The following three open-ended questions were posed to participants:

- What sounds would make you feel a negative emotion?
- What sounds would draw your attention when sleeping?
- What sounds would you feel the need to investigate upon awakening?

Procedure

The questions were put forward to students and staff by two methods:

Firstly, a global e-mail was sent to all staff requesting a reply to the author by return e-mail. The e-mail contained the questions as outlined above, but did not mention that the purpose of the study was to select a new smoke alarm signal because it was thought that this knowledge may limit the range of responses.

Secondly, the researcher (MB) visited a number of undergraduate lectures and tutorial classes in the School of Psychology at the St Albans campus of Victoria University and gathered responses. Once again the purpose of the study was not revealed for the reason stated above.

RESULTS

A total of 1447 individual responses from the 163 participants were received across the three questions combined, yielding over 130 different sounds. Responses varied widely between individuals, with many unusual sounds being put forward only once, for example “Ronan Keating’s latest song” was submitted by one respondent for a sound that would make them feel a negative emotion. Resulting responses were ranked and the top fifteen highest sounds nominated with the highest frequency of response for each question are shown in Tables 1, 2 and 3 respectively.

Table 1.
Top fifteen most frequent responses to question 1, (N = 446).

Question	Rank	Sound	Freq.	% of total
What sounds would make you feel a negative emotion?	1	People yelling	27	6.1
	2	Sirens	25	5.6
	3	People screaming	24	5.4
	3a	People crying/sobbing	24	5.4
	5	People arguing	20	4.5
	6	Any high pitched sound	13	2.9
	7	Sound of a car crash	12	2.7
	7a	Screeching tyres	12	2.7
	9	A baby crying	11	2.5
	10	A child crying	10	2.2
	10a	People in pain	10	2.2
	10b	Gunfire	10	2.2
	13	Any loud sound	9	2.0
	14	Alarm clock	8	1.8
	15	Animals in pain	7	1.6
Total			222	49.8

Examination of the data shown in Table 1 reveals that some of the sounds nominated are very similar in quality, although they were put forward as distinctly separate notions. It was therefore considered useful to further collapse this data to reflect distinct groupings. For this question, most sounds could meaningfully be grouped under two distinct headings:

Expressions of human emotion – including all human sounds nominated; (sounds ranked 1, 3, 3a, 5, 9, 10, 10a giving a total of 126 responses or 28.25%); and
Manufactured alerting sounds- including any synthesised sound produced for the purpose of alerting individuals to a stimulus; (sounds ranked 2, 6, 13, and 14 giving a total of 55 responses or 12.3%).

This leaves sounds ranked 7, 7a, 10b, and 15 (31 responses or 6.9%) to be classified as ‘Others’, although it could be argued that all of these sounds (car crash, screeching tyres, and animal in pain) convey at least the potential for emotional distress of some kind.

Table 2.
Top fifteen most frequent responses to question 2, (N =534).

Question	Rank	Sound	Freq.	% of total

What sounds would draw your attention when sleeping?	1	Child crying or calling out	38	7.1
	2	Loud voices	24	4.5
	3	Dogs barking continuously	22	4.1
	4	Baby crying	21	3.9
	4a	Sirens	21	3.9
	6	Telephone ringing	20	3.8
	6a	Alarms	20	3.8
	8	Alarm clock	16	3.0
	9	Smoke alarm	15	2.8
	10	Loud bangs	14	2.6
	11	Any loud sounds	13	2.4
	11a	Tapping on window or door	13	2.4
	11b	Footsteps	13	2.4
	11c	Glass breaking	13	2.4
	11d	Screaming	13	2.4
	11e	Sounds that don't belong	13	2.4
Total			289	54.1

* Table actually includes 16 responses due to the lowest ranked sounds being nominated an equal number of times.

The responses in Table 2 can be collapsed similarly to those from Table 1 above.

<u>Expressions of human emotion</u>; sounds ranked 1, 2, 4, and 11d, giving a total of 96 responses (18%)
<u>Manufactured alerting sounds;</u> sounds ranked 4a, 6, 6a, 8, and 9, giving a total of 92 responses (17.2%).

The "other" sounds from question 2 are not so easily labeled. It could be argued that the remaining sounds are 'naturalistic alerting sounds', meaning that they would be out of place in the normal quiet of the usual sleeping hours. The assumption is made here that people reporting that such sounds would need to be investigated would find them unusual while they are asleep. The term 'naturalistic' is used here to contrast with 'manufactured', in that they directly relate to the stimulus with which they are associated. For example the sound of footsteps naturalistically alerts us to the possibility of an intruder, in contrast to a manufactured alarm which has been designed to alert a person to the possibility of an intruder.
<u>Other</u>; sounds ranked 3, 10, 11, 11a, 11b, 11c and 11e

Table 2.
<u>Top fifteen most frequent responses to question 3</u>, (N =467)

Question	Rank	Sound	Freq.	% of total
What sounds would you feel the need to investigate upon awakening?	1	Child crying or calling out	31	6.6
	2	A disturbance in the house	29	6.2
	3	Sounds that don't belong	26	5.6
	4	Crying or screaming	22	4.7
	4a	Banging	22	4.7
	6	Glass breaking	21	4.5
	7	Dogs barking continuously	20	4.3
	8	Telephone ringing	18	3.9
	8a	Loud voices	18	3.9
	8b	Footsteps	18	3.9
	11	Alarm sounds	16	3.4

	12	Baby crying	15	3.2
	12a	Water dripping or rushing	15	3.2
	14	Smoke alarm	11	2.3
	14a	Door creaking or closing	11	2.3
Total			293	62.7

This set of sounds can be classified as follows:

Expressions of human emotion; sounds ranked 1, 4, 8b and 12a, giving a total of 86 responses (18.4%).
Manufactured alerting sounds; sounds ranked 8, 11 and 14, giving a total of 45 responses (9.6%).
Naturalistic alerting sounds; sounds ranked 2, 3, 4a, 6, 7, 8a, 8b, 12a and 14a totaling 167 responses (35.8%).

DISCUSSION

Results for all three open-ended questions revealed reasonably uniform categories of responses. When given the opportunity to nominate ANY sound within the bounds of the three questions put forward, people overwhelmingly referred to expressions of human emotion such as a baby crying or a person screaming, followed by manufactured alerting sounds such as a smoke alarm, and by other sounds that may naturalistically alert them to the possibility of danger, such as the sound of footsteps. There was considerable variation within each category, however the most frequent responses correspond well to the categories imposed.

It must be acknowledged that in organizing the data into categories we were guided by previous research and that the data could have been organized differently. However, the categories used captured all the data in a meaningful way and objectively indicated that for all three questions sounds that were either in the ‘expressions of human emotion’ or ‘naturalistically alerting’ categories were consistently ranked among the top first few.

As a result of the distilling process, signals were developed from the ‘expressions of human emotion’ and ‘naturalistically alerting’ categories. No new signal was developed from the ‘manufactured alerting sounds’ category because there were no indications from the responses to question 2 or 3 that such sounds would be more effective than sounds in the other two categories. This decision was also supported by findings from the review of the ergonomic literature (see above) on which sounds were most alerting to people while awake.

The first new signal developed was from the category of a ‘naturalistically alerting sound’. The development of this sound was not simply a matter of selecting one of the sounds nominated because the purpose of this research was to alert sleeping individuals to the possibility of a *fire*. Therefore, the sound selected needed to be situationally congruent, consistent with Gibson’s theory of direct perception (i.e. that a stimulus is perceived more efficiently if its meaning is conveyed directly). This efficiency is important because it allows a person to make swift judgments regarding the appropriate course of action. For example a person hearing the sound of footsteps may be successfully awakened, but then have to process what the sound means from several possibilities, including that it may be a smoke alarm signal. This obviously would make no sense at all. To directly convey the message that there may be a fire in the home the new signal should then be a naturalistic house fire sound. This sound was chosen as the first signal to be tested.

The overwhelming support from this data for a signal conveying an expression of human emotion is compatible with the research that suggests that sleeping individuals will respond best to a sound with emotional significance. Ethical considerations dictated that caution be exercised in the development of this signal because of the possibility of false alarms. It would be socially irresponsible to use the sound of genuine human distress because of the danger of desensitising people as a result of multiple pairings of such sound with no situation of distress or imminent danger, as is the case with repeated false alarms. The second signal developed was a female actor's voice conveying a message about fire.

The process for the development of this signal is outlined in Phase 2.

<u>PHASE TWO – Signal Development and Pilot Testing</u>

Three new signals were developed and tested during phase two of this project including the naturalistic house fire signal and the female actor's voice signal. The third new alarm signal incorporated a shift between the previous two sounds. A signal shift was investigated because, although it has been implied in the research literature that a shifting signal is more effective, this has not previously been investigated. It was thought that a shifting signal may be more successful since studies have noted major individual differences in auditory arousal thresholds[11] and a shifting signal increases the chance that one of the sounds will be perceived and acted upon by sleeping individuals.

The purpose then of Phase 2 was to develop and test the three new signals using a sample of deep sleeping young adults. This group was chosen because they have been found to be less reliably responsive to alarm signals than their older counterparts, and because they have larger amounts of deep sleep. It was hypothesized that the voice signal may have an advantage over the naturalistic fire sound, but not over the signal that shifts between the two stimuli. This is because the signal shift contains elements of *both* sounds, therefore neither sound on its own should be more successful because the signal shift should encompass the aspect that makes the original stimulus successful.

The method will be presented in two distinct sections – signal development followed by pilot testing.

METHOD – Signal Development

Naturalistic house fire

The naturalistic house fire sound was purchased from the website *sound-effects-library.com* (Description – Explosion with glass & fire; Reference – s_378564). It was edited down to 30 seconds duration. It included the sound of glass explosions and the roaring, crackling, and popping of a fire. This sound was selected over a pure fire sound for two reasons. Firstly, because the addition of the glass and explosion sounds added to the naturalistic sound of a fire in a domestic dwelling, and secondly because people who alert emergency services to a fire in a neighbouring residence often report that it was the sound of breaking glass that drew their attention.[28]

The further signals were constructed specifically for the current project.

Female actor's voice
The actor's voice was recorded in a single session using the equipment of the professional radio production suite at Victoria University. She was instructed to use an emotional tone, and speak as though she was alerting a loved one to the presence of a fire (see Barzegar & Wogalter, 1998). Specific direction was given that she should use her voice to emphatically project the emotional significance and urgency of the situation, but without the likelihood of inciting feelings of panic or hysteria. She was further instructed that she must use the words DANGER and FIRE more than once, and that the message should instruct the person to WAKE UP and INVESTIGATE. Several recordings were made of the actor repeating each key phrase or word several times using different vocal intonations on each occasion. A number of different recordings were then made of the actor free-associating a message according to the instructions outlined above. The actor was paid $150.00 AUD for her services plus $10.00 AUD travel expenses.

The resulting message was constructed by editing together the phrases and words judged the most appropriate and emphatic. Words were selected that were spoken with an increase in pitch.[23] The content was as follows:

> "DANGER, DANGER there is FIRE. WAKE UP. You MUST get up and INVESTIGATE, there is FIRE. GET UP NOW!"

The duration of the message was 10 seconds, which was looped into a total of 30 seconds.

Signal shift
The signal shift was constructed by splicing together portions of the naturalistic house fire sound and the female actor's voice. The signal began with a 5 second edit of the actor's voice taken directly from the material reported above as follows:

> "DANGER there is FIRE. GET UP NOW!"

This was followed without pause by a 5 second edit of the naturalistic glass and fire sound that included the roaring, crackling and popping fire noises, as well as an explosion of glass. Total duration of the signal shift was 10 seconds, which was looped into a total of 30 seconds.

METHOD – Pilot testing

The basic methodology employed for the pilot testing was in large parts identical to that used in ongoing research by the same authors which is reported in this publication[29]. The elements relevant to the current study are repeated here.

Participants

Participants for the pilot study were 8 self-reported deep sleepers (4M, 4F). Participants were recruited from amongst the student body of Victoria University, and their friends and family. Ages of participants ranged from 18 to 25 years (mean = 21.63, sd = 2.00) and they were paid $50.00 AUD for each night of testing. Individuals reporting any hearing difficulties, sleep disorders or neurological conditions that may have affected their ability to perceive or respond to an auditory signal were excluded from the study.

Materials

Testing mostly took place in participants' own homes, with the exception of two participants (1M, 1F) who requested that they be tested in the Victoria University Sleep Laboratory to avoid disruption to their families by alarm signals sounding during sleeping hours. The Compumedics Siesta wireless polygraphic data acquisition system was used to monitor sleep staging in all instances. The EEG monitoring was carried out using the Profusion PSG programme on a notebook computer from a room adjacent to the participant's bedroom. An automated sound delivery system specifically developed for this project to initiate and control the alarm sounds was also operated from the notebook computer. Sounds were played from stereo speakers placed on a portable table in the participant's bedroom, and attached to the notebook computer by way of a ten metre extension cord. A Lutron SL-4001 Sound Level Meter was used to measure sound intensity.

Procedure

Data collection was undertaken by the first author (MB) and three research assistants who were Honours or Post Graduate students from the Victoria University School of Psychology at their time of employment.

Speakers were positioned at a distance of at least one metre from the participant's pillow, and at no more than 2 metres. The speakers were joined together with a steel band to ensure their configuration would be standard in all rooms. They were permanently positioned with one speaker placed either side of the sub-woofer. Sound was calibrated at the participant's pillow at the level of 60dBA using a regular beeping sound in the Temporal Three pattern that was played continuously until the desired sound intensity was achieved by adjusting speaker volume so that the sound level meter displayed 60dBA (+/-3dBA).

The behavioural response light was positioned on the bedside table where possible, or in a position that could easily be reached by the participant when in bed.

The participant was asked to be changed for bed prior to electrodes being put in place. Electrodes were attached according to the standard placement set down by Rechtschaffen & Kales.[30] Electroencephalogram (EEG) electrodes were attached at C3, C4, A1 and A2. Electro-oculogram (EOG) electrodes were placed at approximately 1cm above the outer canthus of the eye on one side, and at approximately 1cm below the outer canthus of the other eye, and electromyogram (EMG) electrodes were placed beneath the chin. Additionally, a reference electrode was affixed to the middle of the forehead, and a ground electrode was located at the collarbone. Before electrodes were attached, the skin was cleaned firstly with an alcohol swab, and then with Nuprep abrasive cream. Gold cup electrodes were used for C3 and C4, and minidot snap- on electrodes were used for all others.

All sounds were played to participants prior to them going to bed on the first night. Once the electrodes were in place, the participant went to bed. Prior to lights out they were instructed on the procedure to follow when they became aware of the signals sounding. They were asked to depress the behavioural response button placed next to their bed three times to signify that they were awake as soon as possible after they became aware of the sounds playing. After lights were extinguished, the research assistant monitored the participant's EEG until Stage 4 sleep was confirmed for a minimum of three consecutive 30 second epochs according to the criteria laid out by Rechtschaffen & Kales.[30]Once stage 4 sleep was confirmed the sound delivery system was activated to commence signal delivery through the speakers in the bedroom. All sounds were presented using the 'method of limits' whereby a signal is presented at a low intensity, and then incrementally increased across a predetermined time limit until the participant responds. Sounds were commenced at 35dBA, which corresponds generally to the sound intensity of a whisper, and the volume was increased in 5dBA increments up to a maximum level of 95dBA, which is equivalent to loud industrial noise. The sounds played continuously for 30 seconds at each volume level to allow participants enough time to respond at any given intensity. Each 30 second period of sound was followed by 30 seconds of silence before the sound commenced at the next volume level. When the participant had awakened, the research assistant alerted the sound delivery programme to record the exact time, and the sound was ceased. If there was no response after 30 seconds at 95dBA, the sound continued for a further 3 minutes before being terminated.

All response times were calculated as number of seconds from sound commencement to the first sign of wakefulness which was determined from the EEG. Each author independently examined the EEG trace of all participants to determine the exact times of awakening according to the criteria established by Rechtschaffen & Kales.[30] Both authors then conferred regarding any differences and an exact time was documented.

All statistics were calculated using SPSS version 11.

RESULTS

Means and standard deviations for EEG auditory arousal threshold (AAT) and sound intensity level (dBA) at awakening were calculated for each sound. These are presented in Table 4.

Table 4.
Means and standard deviations for EEG auditory arousal threshold and sound intensity level at awakening to three different signals, (N = 8).

	Naturalistic House Fire		Actor's Voice		Signal Shift	
	M	SD	M	SD	M	SD
AAT (secs)	198.00	172.84	167.00	147.81	203.13	208.85
Sound intensity (dBA)	50.00	14.39	47.50	12.82	51.25	17.47

A number of participants awoke during the periods of silence which emerged as a substantial confound in determining EEG response times. For this reason, statistical analyses which allowed the filtering out of the 30 second periods of silence were used to explore differences between the number of seconds elapsed for each signal to awaken participants. An Analysis of Covariance (ANCOVA) was used to measure differences between the EEG auditory arousal threshold for the three sounds. A significant difference was found $F(2,8) = 4.77$, $p = .043$. Perusal of the means presented in Table 4 show that the actor's voice was the most successful signal, with little difference found between the naturalistic house fire sound and the signal shift.

A surprising element of the data shown in Table 4 is the magnitude of the standard deviation for each sound.

DISCUSSION

Partial support was found for the hypothesis that the voice signal would have an advantage over the naturalistic fire sound, but not over the signal that shifts between the two stimuli. The actor's voice was found to be the most successful, however, there was no advantage for the signal shift compared to the naturalistic fire sound. This was somewhat surprising because the elements of the most successful sound are, by design, an aspect of the signal shift. It is possible that the advantage of the complete actor's voice signal was that the message was more detailed and contained repetition of key words, thereby enhancing both the understandability of the message, and its emotional significance. It is possible that the slower mean response time for the signal shift is more informative about the recommended length of a voice signal when it is to be used to awaken sleeping individuals, rather than the success of a signal shift in itself. Future research could explore the optimal signal length for voice alarms.

Both new alarm signals were thought to have the apparent advantage of directly conveying information, however the voice alarm would seem to have the added benefit of also conveying emotion. Taken at face value, this is a somewhat bizarre assertion because a person who has awakened to find their house on fire would certainly be expected to have some sort of an emotional response. The problem with the naturalistic house fire sound may be that it is not effective in isolation. Since an actual fire would result in stimuli being processed in several sensory modalities simultaneously, perhaps the presence of an auditory stimulus alone is insufficient to produce arousal until it reaches a higher intensity. This would explain the advantage of the actor's voice because the emotion is able to be conveyed equally as directly as the immediately salient information.

It must be noted that this study is preliminary only. The sample size of eight individuals is not sufficient to claim conclusive findings, but is adequate for the purposes of the current study. This is illustrated by the magnitude of the standard deviations of the mean auditory arousal threshold. The substantial figures are accounted for by the fact that the sample size was not sufficiently large to absorb the effects of the considerable variability between individuals, and stems from some participants being awakened at the lowest volume level, while others responded at the higher levels. The addition of 30 seconds of silence between the increments of sound added to this problem. However the results are sufficiently robust considering that the current project serves merely as a pilot study that was designed to select a single new signal that will be tested against existing signals.

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