element™

AntiShock™

IMPULSE CORRECTION FOR TRANSIENT SIGNALS TO ENSURE CLEAR AND COMFORTABLE LISTENING

Executive Summary

AntiShock™ is a patent pending algorithm feature introduced by Unitron Hearing in the Element™ line of hearing aids. AntiShock instantly adjusts the intensity of annoying transients, making them comfortable and natural sounding to hearing aid wearers. Properly controlling transients in a hearing aid requires that three conditions be met. First, the algorithm must instantly detect and suppress the annoying leading edge of the transient. Secondly, it must be corrected without interfering with the clarity and quality of speech. Third, the algorithm must also be adaptive enough to bring any transient into the range of proportionately normal loudness relative to the surrounding speech environment. Acoustic analysis and subjective evaluations on hearing aid wearers has demonstrated that antiShock meets all three requirements. It provides a very natural sound quality that is clear and comfortable without distorting the perception of speech or the target transient.

unitron™ hearing

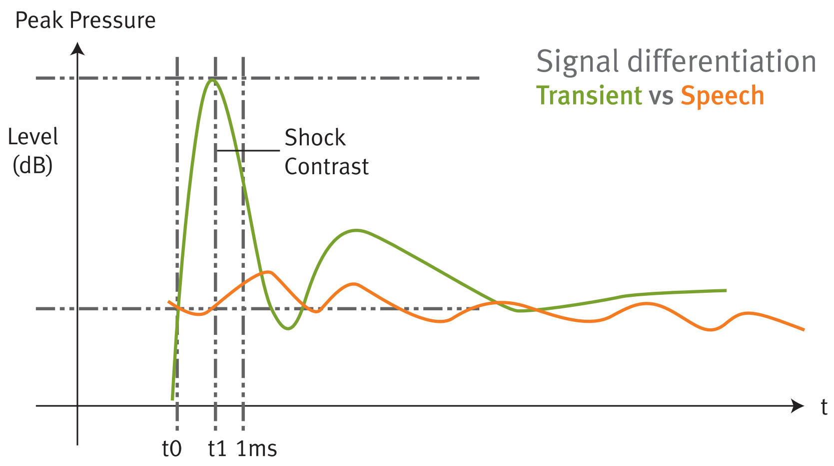
Traditional Approaches for Controlling Transient Sounds

Most clinicians have a standard set of tests they perform to validate hearing aid fittings. These may include real-ear measures or speech in noise tests. A set of non-standard tests are sometimes performed as well. Almost every clinic has a coffee can filled with nuts and bolts, a teacup and spoon or a heavy metal paper weight. These items are all used for one purpose: to generate a loud bang or transient impulse to test the wearer's aided tolerance for such sounds.

Transient sounds consist of an intense pulse of acoustic energy rising well above the long term average of the surrounding environment. They are typically broadband and always brief (transitory) in duration[1, 2]. Aside from the intensity and brevity of transients, they are also characterized by a leading edge that rises extremely rapidly[1]. Figure 1 shows an example of a typical transient sound.

The traditional approach for controlling transients in a hearing aid is through the use of a transient limiter. Such limiters usually consist of nothing more than a peak clipper. Peak clippers are used because they are instantaneous. Therefore, they are fast enough to react appropriately to the quickly rising leading edge of the transient. Traditional automatic gain control (AGC) circuits with attack times of 8 – 10 ms are far too slow to catch a transient that can rise to an intense peak in as little as a few microseconds[1]. However, a peak clipper, being instant, will work for any very intense transients.

Figure 1



Peak clipping has limitations that render it inadequate for many common transients. Peak clipping generates considerable harmonic and intermodulation distortions that degrade sound quality and speech perception. Furthermore, peak clipping can only occur when the hearing aid is at or near saturation. There are many transients such as dishes clattering, keys jingling, car doors shutting or many children's toys that hearing aid wearers find very uncomfortable[3]. However, many are not nearly intense enough to reach the peak clipper. In fact, the rapid rise time of the transient and not just the overall sound pressure level, often causes the annoyance[4, 5]. Hence, peak clipping is insufficient to relieve the annoyance caused by many every day transient signals. Reducing the annoyance of transients or any noises in general is important for three reasons: "First, annoying sounds reduce the over-all quality of human life. Second, annoyance should be seen as a warning of threat to health. Third, annoyance can be seen as a mediating factor in the effects of noise performance."[6]

Statement of the Problem

Controlling transients using traditional approaches has proven ineffective in the past. Most hearing aid circuits adapt too slowly. Those that are fast enough create distortion and are reserved only for very high intensity inputs. To effectively control all transients and provide a comfortable listening experience that maintains good sound quality, the control system must achieve the following objectives:

- **Instantly detect** and control the leading edge of the transient.
- **Never mistake speech for an undesirable transient** and therefore never negatively impact speech perception or quality.
- **Transient control must be adaptive** providing proportionately larger reduction for more intense transients and little or no reduction for weak transients. Thus, a natural sounding relationship is maintained between transients of any intensity with the surrounding acoustic environment.

Once these three conditions are met, the perceived sound quality of the hearing aid goes up dramatically just as the annoyance from transients is reduced.

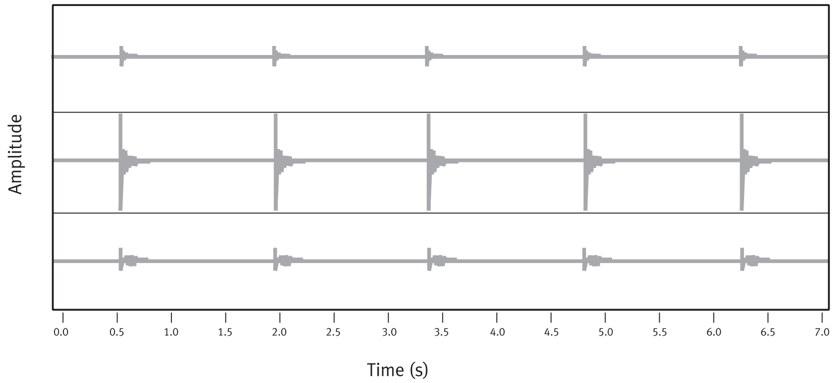
AntiShock™: Adaptively Controls Transients Without Degrading Speech

AntiShock is an entirely new feature for the hearing aid industry that has been implemented across the Element™ line providing seamless adaptive control for transient signals without degrading surrounding speech. This patent pending detection and correction algorithm restores normal loudness perception for transient impulses. AntiShock operates within the time frame at which the transients actually occur. Therefore, it neither distorts sound quality nor effects speech perception.

Instant Detection

AntiShock's intelligent detectors constantly monitor modulations in the incoming signals at the hearing aid microphone. A characteristic transient modulation consisting of a rapidly rising amplitude spike on the order of microseconds triggers antiShock to react. Figure 2 shows the problem associated with hearing aid amplified transients, and how antiShock brings the signal level back under control.

Figure 2



Track 1 (top) of Figure 2 is a recording of a knife chopping food on a hard cutting surface. Five transients can be seen over the course of about seven seconds. The amplitude of track 1 is increased in the figure to make the fine structure of the waveform more visible. This is not a sound that a normal hearing person would find uncomfortably sharp or loud. However, once the signal is processed by a hearing aid fitted to a flat 50 dB HL hearing loss, the leading edge of the transient becomes disproportionately large. Track 2 (middle) shows the same recoded signal after passing through the hearing aid into a 2 cc coupler. Track 3 (bottom) illustrates the same signal passing through the same hearing aid, but this time antiShock is activated. Referencing track 3 to track 1, note how the amplitude of the transient in track 3 has been returned to a more natural level relative to the unamplified recording in track 1.

Figure 2 demonstrates three relevant points about antiShock:

1. AntiShock responded instantly to each transient without the overshoot that would occur had an AGC circuit been used.
2. Bearing in mind that a knife on a cutting board is not an intense transient, the signal level of the leading edge has been reduced proportionately. The sound was neither eliminated nor distorted, merely proportionately reduced.
3. After the leading edge passes, there is a slight undershoot which momentarily alters the shape of the waveform relative to the original. However, the duration of the undershoot is less than 60 ms, shorter than the duration of the damped trailing edge of the transient.

In other words, Figure 2 demonstrates that antiShock responds instantly and proportionately to transients in both the time and amplitude domains. Furthermore, in this example, a release time of 60 ms seems a bit long as it creates a small undershoot. However, it will become clear in later examples that 60 ms is very appropriate for such signals.

Never Affects Speech

Some transients do occur in normal speech. For example, plosives such as /k,t,d/ have a transient burst at the release of air. No speech should be impacted by antiShock, but these phonemes are particularly vulnerable to misdetection due to their transient nature and duration which is less than 60 ms. Figure 3 shows an example of processed and unprocessed speech to demonstrate the impact (or lack thereof) of antiShock on speech.

Track 1 (top) is a recording from a male speaker at an average level of 65 dB SPL. Phonemes /t,k,d/ that occur in the signal are highlighted with color. The amplitude of track 1 has been increased in the figure to make the fine structure of the waveform more visible relative to tracks 2 and 3 which have been processed by a hearing aid. Track 2 is the output of the same hearing aid shown in Figure 2 under the same circumstances. AntiShock is off in track 2. Once again, track 3 shows the speech signal processed by the same hearing aid, but with antiShock turned on. The three salient features of Figure 3 include:

1. Tracks 2 and 3 have waveform morphology that is slightly different than track 1. This is because the hearing aid provided some high-frequency emphasis and altered the phase of the waveform relative to the unprocessed signal in track 1. Therefore, the impact of antiShock can best be seen by comparing tracks 2 and 3 rather than tracks 1 and 3.
2. Tracks 2 and 3 are virtually identical. Thus, engaging antiShock had no effect on the speech waveform.

Listening tests further confirm that there is no audible difference.

3. Although the phonemes /t,k,d/ are transients, they were not affected by antiShock. Note that the amplitude of these phonemes is considerably smaller than the surrounding vowels. AntiShock detects transients that rise above the average level of the speech stream, and therefore does not mistake speech for undesirable transients.

Figure 3

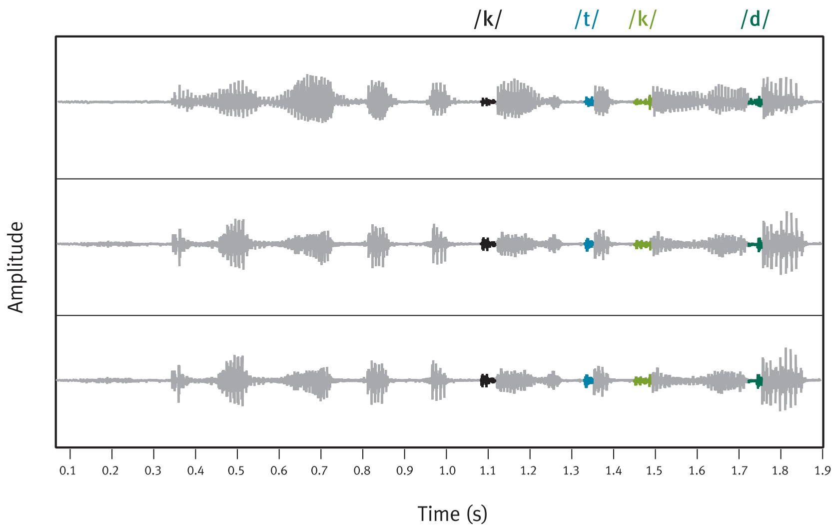


Figure 4

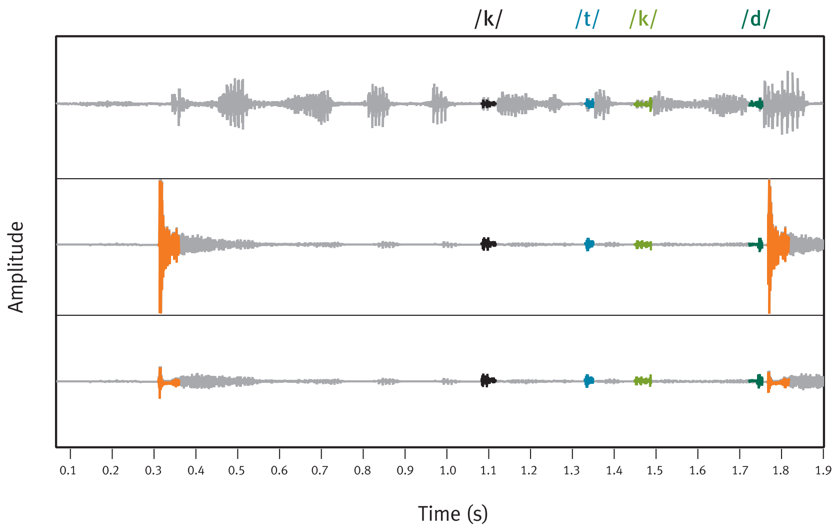


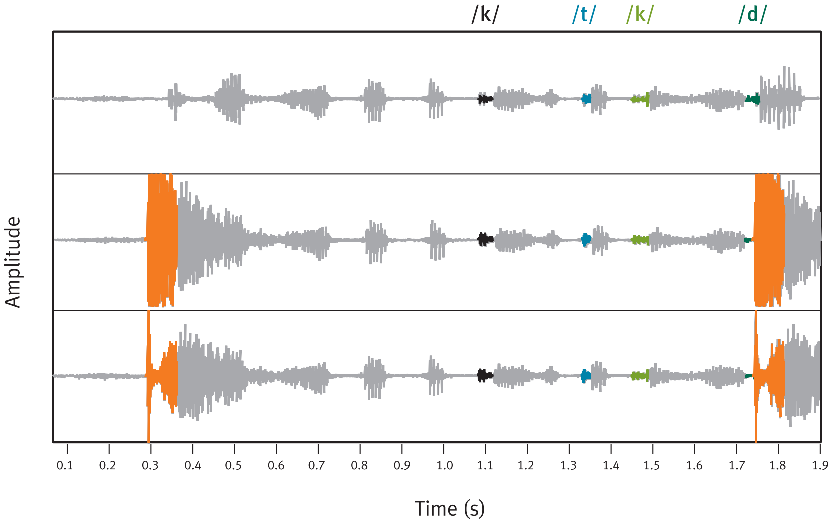
Figure 3 illustrates that clean speech is unaffected by engaging the antiShock algorithm. This begs the question, “Is speech affected by antiShock when transients occur at the same time?” The answer to that question is shown in Figures 4 and 5.

Track 1 (top) of Figure 4 is the same waveform shown in track 2 (middle) of Figure 3: the aided clean speech waveform where antiShock is disengaged. Tracks 2 (middle) and 3 (bottom) of Figure 4 are recordings of the same speech signal in the presence of the knife transient from Figure 2. Track 2 shows the amplified signal of the speech plus the knife transient with antiShock off. In track 3 antiShock is on. In this figure, the amplitudes of tracks 2 and 3 have not been normalized to show the speech. In this way it is possible to see the full amplitude of the knife transient relative to the average level of the speech signal once it has passed through the hearing aid.

Ignoring the speech for a moment, observe the amplitude and duration of the leading edge of the initial transient in track 2, which rises to its peak amplitude in under 1 ms. The duration of the most intense portion of the pulse (colored) is approximately 15 ms. After the first 15 ms the amplitude of the transient is quite significantly damped but still large relative to the speech that follows it. In track 3 the amplitude of the transient is still larger than the following speech, but it has only been reduced enough to reestablish a correctly proportioned relationship between the two. In other words, the transient is still audible, and it still sounds like a knife on a cutting board. However, it no longer sounds disproportionately loud to the hearing aid wearer compared to a normal hearing individual.

Figure 5 shows the same three tracks as Figure 4. This time tracks 2 and 3 have been normalized relative to track 1 so that the speech waveforms can be seen more easily. Once again, except where there is a transient present, tracks 1, 2 and 3 are virtually identical. Track 1 does not show any transients to allow a comparison of the amplitude of the amplified speech to the transient that occurred at the same time in tracks 2 and 3. In this figure, it is easier to see the relative levels of the uncontrolled and controlled transients in tracks 2 and 3 respectively compared to the average speech signal level in track 1. Note how antiShock controls the leading edge of the transient just enough to reduce, but not remove it. The algorithm releases before the trailing end of the transient to maintain normal perception of the knife sound relative to the speech that follows. The complete release occurred just under 80 ms after the leading edge of the transient passed.

Figure 5



Adaptive Control

For a balanced perception of transient to speech to be maintained for all shock sounds, the controlling algorithm must be adaptive. If it is static, it may not be strong enough to control very intense transients such as a door slamming. A static system may also be overly aggressive for soft transients such as a pen tapping on a table. The goal is to allow the hearing aid wearer to perceive a car door slamming or a pen tapping just as a normal hearing person would. Neither sound should be distorted, completely suppressed, or missed.

Earlier examples showed how well antiShock controls a moderately intense chopping sound. The flexibility of antiShock to more selectively control soft transients is demonstrated in Figure 6. Track 1 (top) is a recording of the original 65 dB male speech signal that has been normalized to show the fine structure of the waveform. Tracks 2 and 3 below it are recordings of a pen tap recorded through an Element 16 BTE along with the original speech signal from track 1. In track 2 antiShock is turned off, and in track 3 it is turned on.

The morphology of the waveforms passed through the hearing aid look slightly different than the original, for all the same reasons mentioned previously. When track 2 is compared to track 3, the speech signal is entirely unaffected by antiShock. Furthermore, even the pen tap is passed with very little effect. AntiShock causes a very minor reduction of the leading edge for about 2 ms. Otherwise, the pen tap and speech are passed with no effect at all. Compare this result to another approach to transient reduction that relies on a filtering technique.

Filtering may be used to smooth a transient in much the same way as noise reduction can be used to reduce the level of longer duration signals relative to speech. A typical noise reduction algorithm would have time constants that are too slow to react to a transient input. However, filtering can control the leading edge of transients, but there are two problems with current filtering methods:

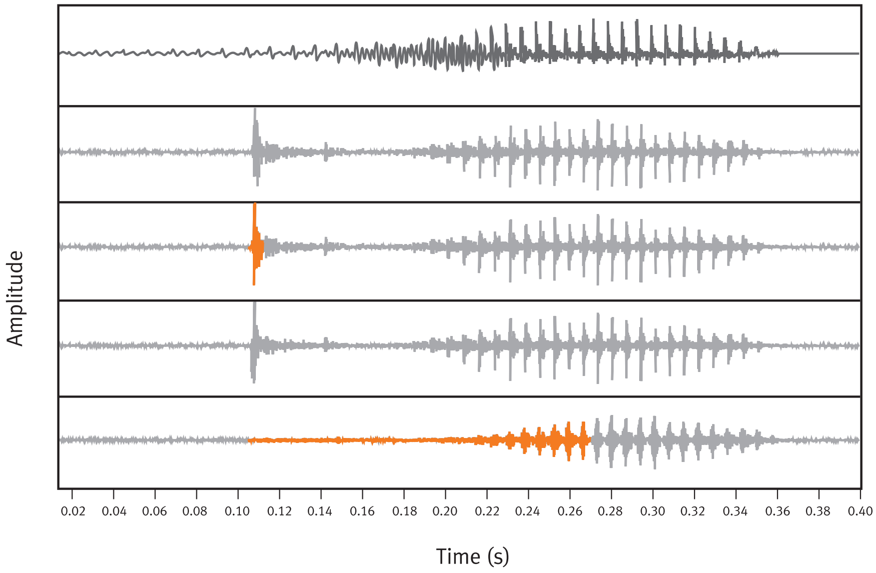
1. They are not adaptive enough, requiring the use of a threshold control to stop the hearing aid from reacting too aggressively on soft transients.
2. While the attack time may be adequate to catch the leading edge of a transient, the release time is so long as to distort the speech surrounding the transient.

Tracks 4 and 5 of Figure 6 demonstrate the effects of the filtering method on a transient in the presence of speech. Another hearing aid was adjusted to approximate the output of the hearing aid used for tracks 2 and 3. The original signal is processed through the second hearing aid without transient filtering in track 4. The result with transient filtering engaged is shown in track 5 (bottom). Bearing in mind that the transient in this figure is a fairly soft pen tap, the goal is to pass it through the hearing aid without output reduction. However, track 5 shows a different outcome in two dimensions:

1. The sound of the soft pen tap is completely eliminated by an overly aggressive filtering algorithm.
2. The speech signal after the pen tap is substantially reduced for approximately 180 ms after the leading edge of the transient from the pen.

This means that the filtering approach, as applied here, does not adapt appropriately across the range of possible transients.

Figure 6



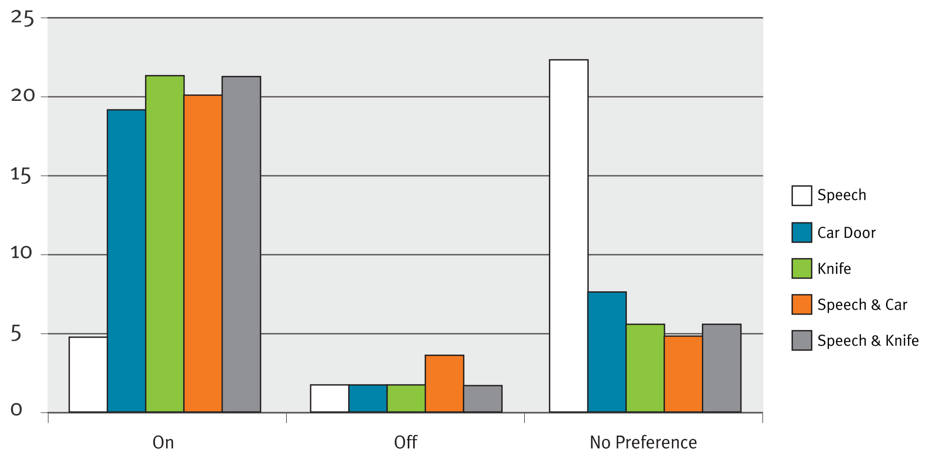
Furthermore, because of the long release time, it distorts speech well after the transient has passed.

Hearing Aid Wearers Prefer AntiShock™

The previous figures demonstrate that antiShock performs as desired for speech, transients and speech plus transients. However, it does not show if hearing aid wearers prefer this new feature. To answer this question, a blind comparison was undertaken. Thirty participants with varying degrees of hearing loss were fitted with Element hearing aids of multiple shell styles. They listened to recorded speech and recorded transients separately then together. They heard each recording with antiShock turned on and turned off in randomized order. Then they informed the tester as to which they preferred. They could give one of three responses that amounted to a preference for antiShock on, antiShock off, or no difference. The results are shown in Figure 7.

The paired comparison results agree with the acoustic measurements shown in the earlier figures. When listening to speech alone 23 of the 30 participants had no preference. They could not tell whether antiShock was on or off. Five people preferred it on and only two liked it off. However, in the other four conditions where transients were presented either alone or with speech, there was a strong systematic preference for antiShock to be on. Between 20 and 22 people preferred antiShock to be on in the presence of a car door slamming or a knife chopping. Only two people preferred it off, four people in the case of speech plus the car door. A small minority had no preference. This example shows that antiShock does meet the three criteria for an adaptive transient limiter, and provides superior performance in the presence of transients.

Figure 7



Further External Validation

A multisite study was undertaken to further test the efficacy of, and obtain more detailed information about, antiShock. To date, a total of 23 participants across both sites have been tested and some of the preliminary results are reported below.

Each participant provided paired comparison and magnitude difference ratings for antiShock on versus antiShock off. The sound attributes under study included sound quality, annoyance and speech clarity. The first judgment was a paired comparison for dimension preference. The listener indicated which of two settings was preferred in terms of the test dimension under study. The second judgment involved rating the magnitude of change in the sound quality dimension between the first and second settings on a scale between 0 and 10 in steps of 1. A rating of 0 meant there was no difference between the two stimuli on the test dimension, and a rating of 10 meant that the two stimuli were extremely different on that dimension. Within each dimension, the comparisons and ratings were repeated three times and averaged.

The number of comparisons was exhaustive, and the data is still somewhat preliminary. Therefore, only the most important dimension of antiShock will be reported here, that of annoyance. The following three Figures 8 – 10 show the participants' preferences for antiShock on versus antiShock off, with regard to the annoyance of the signals they were comparing. Each figure shows how many participants preferred it on/off for each signal.

Figure 8 shows the outcome when transients alone were presented without the context of speech or noise. The results were the same for all four signals from the softest (pen taps) to the loudest (car door). The participants from both sites overwhelmingly preferred antiShock on. Furthermore, the results from both sites were almost identical on every comparison of all three figures. The trends were consistently the same for the two locations.

Figure 8
Preference for antiShock - Transients in Isolation

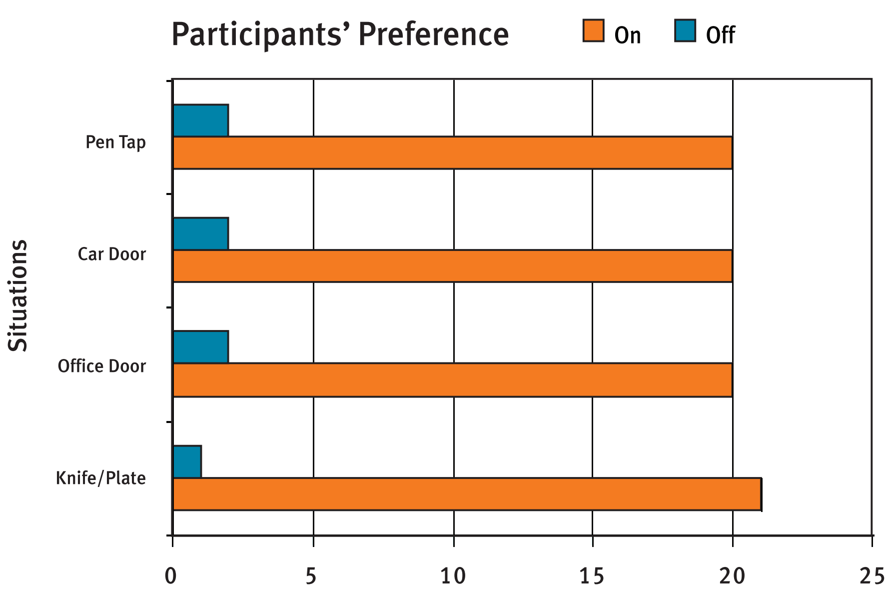


Figure 9 shows the outcome of the comparisons when the transients were presented in the presence of speech. To limit the number of comparisons for the participants, only the office door (O.D.) and knife on a ceramic plate (K.P.) were used. For each of the two transients, speech was presented at two levels: soft (52.5 dB) and loud (75 dB). Figure 9 shows the participants' preferences when mild, moderate and maximum antiShock settings were tested with each speech level. Once again, antiShock is overwhelmingly preferred, regardless of the setting. One other general trends is also apparent. In the

Figure 9
Preference for antiShock -
Speech (Soft = 52.5 dB, Loud = 75 dB) Plus Transients

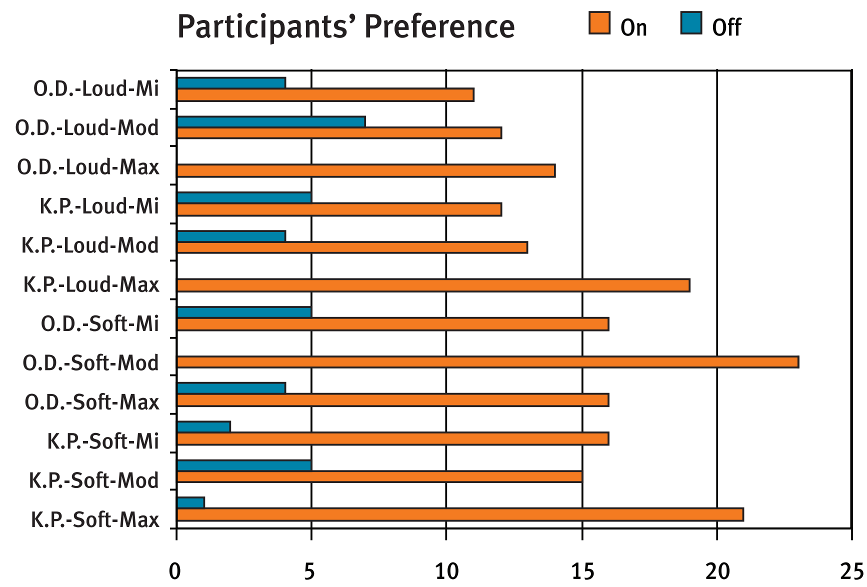
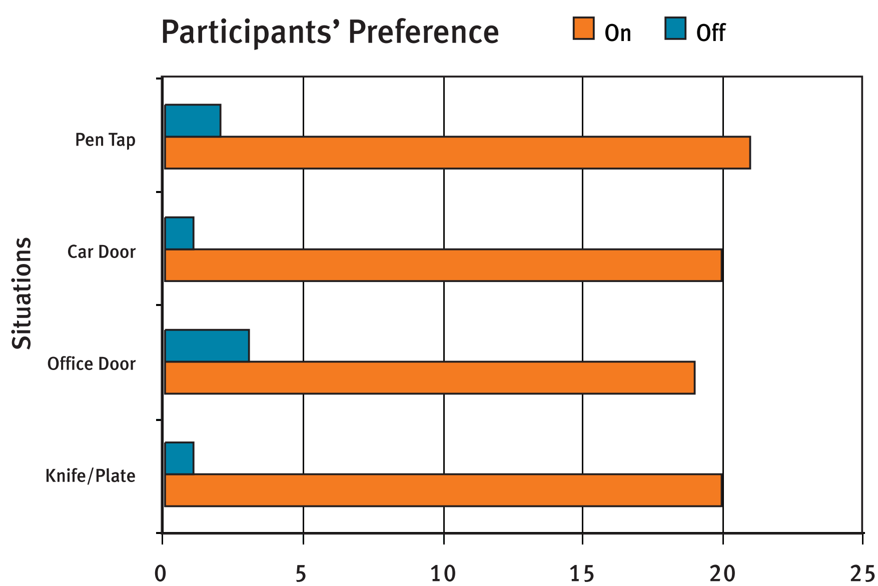


Figure 10
Preference for antiShock -
Average Speech in Babble (10 SNR) Plus Transients



presence of very loud speech, slightly fewer people preferred antiShock on. This is because the transients were not too high above many of the speech peaks in these comparisons. Therefore, by design, the effect of antiShock will not be so great. If the transient is not substantially above the average signal level, antiShock should be less effective.

Figure 10 shows the preference for antiShock when transients are presented in the presence of both speech and noise. In this case, speech was presented at 65 dB SPL and a speech babble noise was presented at 55 dB SPL. Once again the results are unequivocal. The preference for antiShock on was nearly unanimous in every condition.

In other words, there is a substantial reduction in the perceived annoyance caused by the hearing aid when antiShock is engaged. This perception persists even in the presence of the most annoying sounds to which most people will ever be exposed. The preference for antiShock, in the presence of transients, is consistent and substantial demonstrating a measurable reduction in annoyance. This result is contrary to a recently reported noise reduction experiment that showed amplification increased perceived annoyance levels[7]. The enormous preference for antiShock is due to its ability to eliminate annoyance due to transient inputs.

Summary

Properly controlling transients in a hearing aid requires that three conditions be met. The algorithm must instantly detect and suppress the leading edge of the annoying transient without interfering with the clarity and quality of speech. The algorithm must also be adaptive enough to bring any transient into the range of proportionately normal loudness relative to the surrounding speech environment. Acoustic analysis and subjective annoyance evaluations on hearing aid wearers demonstrates that antiShock meets all three requirements. AntiShock provides a very natural sound quality that is both clear and comfortable without distorting the perception of speech or the target transient.

Bibliography

1. Henderson, D. and R.P. Hamernik. (1986) Impulse noise: critical review. The Journal of the Acoustical Society of America, 80(2): 569-84.
2. Voigt, P., B. Godenhielm, and E. Ostlund. (1980) Impulse noise - measurement and assessment of the risk of noise induced hearing loss. Scandinavian Audiology. Supplementum, (Suppl 12): 319-25.
3. Hellstrom, P.A., H.A. Dengerink, and A. Axelsson. (1992) Noise levels from toys and recreational articles for children and teenagers. British Journal of Audiology, 26(5): 267-70.
4. Fidell, S., L. Silvati, and K. Pearsons. (2002) Relative rates of growth of annoyance of impulsive and non-impulsive noises. The Journal of the Acoustical Society of America, 111(1 Pt 2): 576-85.
5. Hiramatsu, K., K. Takagi, and T. Yamamoto. (1983) Experimental investigation on the effect of some temporal factors of nonsteady noise on annoyance. The Journal of the Acoustical Society of America, 74(6): 1782-93.
6. Dornic, S. and T. Laaksonen. (1989) Continuous noise, intermittent noise, and annoyance. Perceptual and Motor Skills, 68(1): 11-8.
7. Palmer, C.V., R. Bentler, and H.G. Mueller. (2006) Amplification with digital noise reduction and the perception of annoying and aversive sounds. Trends in Amplification, 10(2): 95 - 104.

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