Compression Basics: An Overview
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- [Luis] And that'll bring us right up to the top of the hour. We're ready to begin our session here today at Audiology Online. I'm gonna start off first by introducing myself, my name is Dr. Luis Camacho. I am senior audiologist with the Education and Training Department at Starkey Hearing Technologies, and I will be your host for today's session. Today we're gonna really kinda just take a step back and talk about compression. I know most of us have, probably all of us that are online here today, deal with compression every single day when we're working with hearing aids and working with patients, but I think it's always a good idea to step back and kind of review the basics, remind ourselves exactly what we're working with when we're dealing with compression in today's modern hearing aids.

I also want to thank everyone who's online, I know it can be difficult sometimes to get away from your busy work days, and we at Starkey Hearing Technologies do appreciate you taking the time and joining us here at Audiology Online. Before we jump into today's session, I just have a few housekeeping items to run through. First of all, if you're having any technical problems, interacting, viewing, hearing today's presentation please stay logged on and contact Audiology Online at 1-800-753-2160. Sometimes if you're running too many software or applications simultaneously, that can cause interference with the system. So you may want to take a moment to shut everything else down that you're logged in to, and just stay logged in here to the Audiology Online classroom. But, again, if you continue to have problems, call Audiology Online at 1-800-753-2160.

Today's session is available for one CEU credit. To earn the credit you must stay logged on for the full session. As typical, we're scheduled for one hour today. And then you will need to successfully complete a short quiz after the end of today's session. Shortly after the end of the session, if you log back in to your Audiology Online account, you should see this course listed as a pending course, and there you will have access to the quiz. It's a 10 question multiple choice quiz on today's materials.

We do have four learning objectives for today's course. At the end of the session you should be able to identify the different types of compression. You'll be able to define what a compression threshold kneepoint is, define a compression ratio, and also know the rationale behind wide dynamic range compression. If you do have any questions throughout today's session, please feel free to ask those. Just type in your question there in the chat box, hit your enter key, and that'll send the question on to me via the chat area. It is useful for me, if you do type in a question, if you could also click on the hands up icon just below the chat box. That'll just send a little audible indicator to me. It draws my attention over to the chat box and makes sure that I don't miss any questions that come up throughout the session. Lastly, in the file share area you will see a PDF handout of today's presentation. If you just click on the title you'll see the download files button become active and you can click on that and you'll be prompted to download and save the PDF for your future reference.

So let's go ahead and jump in. And as I said, this is going to be kind of a basic overview on the concepts of compression. And one of the common questions that comes up, and you'll sometimes get into this discussion with your patients as you're either describing what today's modern hearing aids can do, or in your fine tuning, in your fitting and adjustment process, exactly what you're doing to provide the best sound quality, the best comfort, and that is why do we utilize a compression structure, or a compression architecture in hearing aids today. And really it comes down to the fact that as we move about our everyday lives we're in a lot of different environments. We're exposing ourselves to a lot of different types of sounds, and particularly a lot of different levels of sounds. So again, it might be sitting alone in the kitchen drinking a cup of coffee, reading the newspaper when you first get up in the morning. It might be going for a walk, in the car, you're out in a crowded restaurant, you're walking the dog and there's traffic, and a huge range of sounds, some of which your patients specifically want to focus in on, others they maybe don't want to pay attention to at all, or don't even want to be aware of.

And this wide range of sounds and intensity of sounds is really where compression comes in, and the importance of compression and all the various characteristics of compression in today's hearing aids. So when we're talking about these different levels of intensity, what we really are thinking about and focusing in on with human hearing is what we call the dynamic range of a person's ability to hear.

So when we talk about a dynamic range, we're really talking about what is the softest sound that a person can perceive, all the way up to the sounds that are incredibly loud and then go beyond the point of comfort, where it's too loud. In a normal hearing person, and you've got everything from the softest, softest sounds, rain, the hum of a computer fan, very, very low level sounds all the way up to really super intense sound levels. And if we kind of draw that out on what we're used to looking at every day in the hearing industry, and that's our audiogram. Someone with a normal hearing would typically have, kind of on average, a dynamic range maybe about 110 decibels. Again, from the point of barely perceiving sound across the various frequencies that we look at as hearing healthcare professionals to the point of discomfort.

A point where we don't want things to get any louder, either for comfort or, obviously, dangerous intensities. So this would be a typical dynamic range of someone with normal hearing. But obviously we typically, in our day-to-day businesses, our day-to-day interactions with patients, we aren't usually working with people with normal hearing. We're working with people that have some type or some level of hearing loss. And really here's where we're getting into the crux of the idea of compression and why we even utilize compression in hearing aids, and that's how a person's dynamic range changes with hearing loss.

And in particular, we're talking about sensorineural hearing loss. You've got whole other conversations when you're dealing with mixed losses, or losses that are caused by ear infections, et cetera, et cetera. But when we're dealing with sensorineural hearing loss, we're typically working with a reduced or a limited dynamic range. So if we look at this similar graph here, we see that those softer, or those weaker sounds are now, obviously, inaudible. And then the moderate sounds become, kind of the point of threshold. Yet loud sounds, or the intense sounds, the sounds that are at the point of discomfort, those don't shift upward. We don't move up to a higher intensity for those loud sounds. Someone with a hearing loss doesn't have an increased tolerance for loudness.

So we typically talk about how for people with a sensorineural hearing loss, their dynamic range is reduced and they actually get a perceived more rapid growth of loudness. Because again, if we kind of look at kind of the typical hearing loss, and this is obviously very, very rudimentary, we're dealing with a flat hearing loss here, we're not putting any unusual shapes or ski slope losses, but just to illustrate the point, you might now have somebody that has the point of threshold, the softest sound they can here is around 40 dB, yet as you can see, the loud sounds still hit that point of discomfort, high intensity, still at 110 decibels in this example, meaning their dynamic range is significantly narrowed.

And so you do get this perception that sounds get loud faster than for someone with normal hearing. Again, here's where we run into the problems of kind of a typical hearing aid fitting is that things get loud quickly, you can't just turn the volume up for every sound and expect the patient to be able to be comfortable in every different environment. And this change in dynamic range, this change in perception of loudness is what's known as recruitment where, again, the patient perceives the sound's getting louder more quickly than someone with normal hearing, if they're got a sensorineural hearing loss.

And I think the difficulty is we want to mimic this wide, broad dynamic range of normal hearing that's what we have in an intact auditory system. We need to mimic that within the structure, the function of the amplification process within the hearing aid that you're fitting to the patient. And kind of a good analogy of this is you're trying to squeeze an elephant into a suitcase. You're trying to take that 110 dB dynamic range in everything from the sound of leaves blowing in the wind or, again, the hum of your computer, to the bang of fireworks on the Fourth of July and everything in between, that's your elephant, and you're trying to squeeze it into the suitcase, which is the patient's narrowed dynamic range.

And that can be difficult, as I'm sure you all have worked with patients that have had very, very narrow dynamic ranges that their point of discomfort, their UCLs, the highest end of their dynamic range actually is come down to a lower point compared to someone with normal hearing. And this is where compression was really designed, was to at least put a cap, if you will, on super loud sounds or at the point of discomfort for patients. So we want to take, again, in our kinda simplified diagram of 110 dB dynamic range down into a 60 dB dynamic range. We want to shrink all of those sounds from the softest to the most extreme loud point of discomfort into that narrow area and obviously provide amplification, provide audibility for those soft sounds but not let the then successively louder sounds go up beyond to the point of discomfort. And that's really the whole reason that any of the hearing aids that you work with today have a compression architecture.

And obviously there are benefits beyond just comfort when we're working with today's digital hearing aids that have multiple compression regions, et cetera and we'll focus in on that a little bit as we go through the session today as well. So, again, bottom line when we're working again really we're talking about sensorineural hearing losses is that we want to make sure that soft sounds, and particularly when we're working with patients with our hearing aids today, we're talking about soft speech input, but just generically we want to make sure that soft sounds are made audible, that we've got some audibility for that, obviously then the ability to understand speech is usually primary when we're using, fitting hearing aids with our patients. We want to make sure that loud sounds don't become uncomfortably loud, and we need to keep that narrow dynamic range into consideration so we're not just turning everything up, so we want to bring up the volume for soft sounds, we want to make sure we're keeping loud sounds from becoming too loud and to the point of discomfort, and we want to try and, again, focus in on speech, make sure that speech is at a comfortable or what the patient would perceive as a, quote unquote, normal volume in conversation with people throughout the day.

Now, that's kind of the goal of your ideal hearing aid fitting. And this is where we get into this question of kind of, well what's the most important thing to focus in on when working with our hearing aid patients, when we're working with our patients that have hearing loss and we're wanting to fit them with hearing aids and get the maximum performance, clarity, comfort, et cetera? You say, what's most important for them to hear? And, again, usually with hearing aid fittings we're focusing in on conversational speech, and with most of the hearing aids today, the first focus is on soft speech inputs. And we're all familiar with this speech banana type graph, kind of spreading out the average intensity of the various speech sounds. And I know when I fit hearing aids with patients and I discuss, go over audiograms, this is usually one of the first things that I will show a patient is here's why you're having the difficulty understanding speech with your spouse or your kids or your grandkids or your coworkers or whoever that they're having difficulties with based on the shape and the severity of their hearing loss, 'cause, you know, they're missing certain speech information, they're losing the audibility to sounds, and very commonly it is the high frequency sounds.

And that's what we talk about, well, this is what we want to focus in on initially with a hearing aid fitting, is bringing audibility back to these particular speech sounds so they can understand a conversation with the people that they, their friends, their loved ones, their coworkers, the people that they really need to hear and understand, as well as on the phone and with television, et cetera, et cetera, et cetera. So this is typically the, kind of the primary focus with most hearing aids today and that gets into the specifics of compression architectures and how the various components of compression can focus in on getting maximum audibility for those soft speech inputs.

So let's just start again kind of from scratch when we're talking about signal processing with hearing aids. And the most kind of rudimentary approach is a linear approach to amplification. And just say today, it's pretty uncommon to work with a straightforward linear approach of amplification just because we obviously, we know more about how the auditory system works, but we also have more tools at our disposal with today's digital devices. And a linear amplification is pretty well defined just in its title, essentially you turning up the volume, and that's usually how, if this kind of discussion comes up with a patient, that's how I talk about it. It's as if you were just going over to the television or the stereo and just turning the dial up, everything goes up in the same amount. And when we talk about the compression ratio, and we'll define that specifically as we move along, but you'll usually, you'll see this represented numerically in a one-to-one relationship, meaning one decibel of sound coming into the amplifier, into the hearing aid, basically equals one decibel of gain coming out of the receiver, out of the speaker, and therefore you get this kind of linear growth across the input/output curve, everyone's favorite graph to look at.

How much goes in, and then going up to see how much comes out. And when you're talking about linear amplification, it's this one-to-one relationship, one dB in essentially results in one decibel of gain out of the receiver, out of the speaker of the hearing aid. Now, you'll notice, actually let me go back real quickly, that with, again, your kind of basic amplifier, we're talking about very basic, almost primitive form of amplification, this doesn't just continue on infinitely, there is a point in which no more gain can be pulled out of the hearing aid, no more amplification can be pulled out of the hearing aid, and that's just because of the limitations of the amplifier and the receiver of the device. And when you hit that maximum point of amplification, what's known as the maximum output of the device, you then can potentially into what's called peak clipping.

So essentially the hearing aid can't provide any more amplification and some of the signal just gets chopped off and then leads to distortion, poor sound quality for the listener at those extreme high outputs. So if you're looking at, again, two graphs of this, you've got the signal coming in, we hit the amplifier of the hearing aid, and it's just turned up however much it needs to be turned up in that particular amplification process. But when you put in a louder sound, it gets turned up, in that linear fashion you're gonna hit a point of where you're gonna cut off or clip the signal, and that, again, is going to lead to distortion and poor sound quality of the device. And this is a side effect of this kind of straightforward linear approach is at some point the amplifier can't turn things up anymore.

Now, linear amplification was obviously used for a long time, I mean this was the basic philosophy of hearing aids and when they were initially developed was, well, let's just turn things up for someone that has a hearing loss. And for certain types of sounds that is perfectly fine. For certain types of hearing loss, again, it can be appropriate. But for most people with your sensorineural types of losses there are pretty extreme limitations of a linear approach. In many cases, average conversational speech now gets too loud, because we're not focusing specifically on soft speech. Yes, soft speech gets turned up and is made audible, but the volume of someone just talking to them at a normal level is turned up an equal amount and now that's uncomfortable or abnormally loud for the patient and obviously as we keep looking at louder and louder and louder inputs, those sounds become, go up to a point of discomfort, potentially even painfully loud, and then at some point you run into peak clipping.

Most people with sensorineural hearing loss will find the, a linear approach throughout the day not comfortable. There's gonna be times when things are too soft or things are too loud, having a point of just kind of average comfort is not usually possible with linear hearing aids as people move throughout their everyday life as we started this off, today's session off with all the different types of sounds that patients get into, soft, loud, extremely loud noise, et cetera, et cetera. Linear just for most people is not appropriate because it's very, very limiting in terms of what we can do with the amplification. Now, that doesn't mean you will throw linearity out the window completely. You will still even today, even though digital hearing aids and compressed hearing aids have been around for a long time, you may still run into a patient that's been wearing linear technology for many, many years. Those patients sometimes will have a difficult time kind of converting, if you will, to compressed sound quality, and may really have essentially trained their brain to utilize the distortion for speech understanding and sound awareness. So sometimes patients that have used linear products for years and years will prefer to stay in a linear approach. Many times this will kinda go hand in hand with patients that have severe to profound hearing loss, because, again, especially if they're an adult and they've been wearing a hearing aid for their whole life, they're probably been wearing linear hearing aids their whole life. And with that severe to profound hearing loss and are going to just want to continue with that kind of high intensity, even distorted sound quality. And, of course, conductive and mixed hearing losses, in many cases a linear approach will work fine, particularly when you're dealing with a pure conductive loss, because their dynamic range really hasn't been typically reduced, we just need to get the sound through whatever is causing the conductive component of the loss, you know, get an ear infection, otosclerosis, whatever it might be, but they don't have the effect of the sensorineural hearing loss that causes that reduced dynamic range.

So, again, typically with your pure conductive losses you can go straight linear and just turn everything up and that's all they need. Mixed losses you might need a little bit of both, but, again, sometimes it is just a matter of getting the sound kind of through that conductive component and the auditory nerve, the neural part of it, the sensorineural part of it hasn't had as much of a reduced dynamic range. So, again, just because the basic of linear approach isn't ideal for most patients, that doesn't mean there aren't gonna be times when you're gonna utilize it, 'cause there will still be times when linearity is going to be appropriate.

So then, of course, we move into a non-linear signal processing, and here's where we start to get into kind of basic compression and then we'll evolve into obviously highly advanced compression in today's digital hearing aids. So kind of your basic compression terms, you've got your compression threshold kneepoint, the compression ratio, which we've kind of dance around a little bit when we were talking about the linear approach, attack and release times, and output compression. We'll throw into here later also the term expansion which I think is kind of a, it's a cousin, if you will, of compression, and we'll talk about that as we move forward a little bit also.

But let's start with the compression threshold kneepoint, and this is essentially the intensity, the point at which a compression approach is going to activate. Some people refer to this as a compression threshold in terms of, and use the, this kind of algorithm or abbreviation CT. I'll be honest with you, when I was in school and I was learning about compression I never used the CT acronym or abbreviation, it was always the TK. So as I'm going through today's presentation, you'll probably most of the time hear me refer to this as the TK or the threshold kneepoint. And the other thing is that in today's hearing aids, we're really not just dealing with one kneepoint. To kinda age myself, as I was coming through school as an audiologist and obviously then fitting patients in a clinical setting, we were dealing with single kneepoint devices, trem pots, very obviously basic compression approaches.

Today, we're looking at kneepoints across 24 different channels, but the core concept remains the same in the sense that you have a point, an intensity point, a volume point in which compression is activated. So if we look at, again, a couple of different curves in an input/output graph here, the kneepoint, again, defines the point of intensity where the hearing aid goes from linear amplification, again, this is kinda your basic approach for compression, and then begins to go into compression. So we just got a couple of different input/output curves here for different hearing aids, and hopefully it's not too small on your screen, but you can see there's one hearing aid where you've got amplification linear and then you hit your kneepoint here and then you go into compression. And then this kind of blue, dark blue one, you get a longer area of linearity and then it goes into compression.

So that kneepoint, again, kind of controls or defines the point at which linear amplification ends and then the hearing goes into compression. And that essentially, really a couple of things, that's kind of the core decision, if you will, with kneepoints, is where do you want linearity to stop and compression to begin? You might set a higher kneepoint on, for a patient that has, again, more severe hearing loss because they can tolerate or they're used to more linearity. Or, again, someone who's worn hearing aids for a long time that's used to kind of a more linear sound quality, but maybe you know or they, through your testing, through their discussion with you, that their does come a point where things become uncomfortably loud for them, that might be where the kneepoint is then set for compression to provide an area where it's no longer amplifying linearly and it's not going into a point of discomfort. That obviously rolls into kinda the second basic characteristic of compression, and that is the compression ratio. So your kneepoint defines when the signal goes into compression, the ratio essentially defines how much the signal is compressed.

And we've already mentioned that a linear amplification is a one-to-one relationship or a one-to-one ratio, again, one decibel in equals an additional decibel of gain out. When we're talking about compression ratios, it's always 1.1 or higher to one, meaning in this example it takes a 1.1 decibel input to equal one dB of gain out. And you'll obviously see compression ratios of anywhere from 1.1 upwards to three-to-one, depending on how much you or the design of the hearing aid or the design of the fitting formula that you're working with, how much compression those approaches, those manufacturers, those fitting formulas kind of define in their approach to amplification and compression.

So, again, if we take a look at a compression ratio here on your input/output graph, you've got that area of linearity in this example, and then we come up and we hit that kneepoint, and beyond that we now move into a two-to-one ratio. So we've got a one-to-one ratio for linear, we hit compression, so in this example it's at 50 dB input, that's your kneepoint, and then anything above that it takes two decibels of input to equal one decibel of gain. So you can see how now the curve is a little, or the graph, not the curve but the line, the graph is kind of shallower, it's not quite as steep as in the area of linearity. So, again, when we're talking about the compression ratio, there's different things to consider, things that are taken into consideration from manufacturer's point of view in terms of their core philosophy of compression, as well as like in fitting formulas, and those fitting formulas' core philosophies of how a hearing aid should sound to a patient with different types or intensities of hearing losses.

So low compression ratios generally will lead to an improved audibility for soft components of speech, again, that's kind of the core ideal of today's hearing aids, and restore that gradual growth of loudness. And usually are better for your mild hearing losses, your newer hearing aid wearer. They could potentially over amplify some of the softer sounds that maybe are brought in and maybe aren't as perceived as important for the patient. But lower compression ratios generally have a more natural sound quality than your higher compression ratios. Now, higher compression ratios will potentially provide more comfort because we're obviously kinda clamping down on gain a little bit more aggressively. However, that could adversely affect the sound quality. What you'll a lot of times with high compression ratios and me, when I'm usually talking about higher compression ratios, I'm talking about anything really maybe at a two, 2.5 to one or higher. Many times you'll lead that to a more muffled or kind of sometimes patients will refer to it as a mushy sound quality, things aren't as sharp or as clear as they want them to be, again, you'll have a lot of comfort to sound because nothing is really ever gonna get over amplified with these higher ratios, but adversely you might run into sound quality issues, muffled, mushy, not clear sounding.

And, again, this is a lot of times dependent on the manufacturer you're working with or the fitting formula that you're working with, and we'll talk about different fitting formulas as we move forward as well. Now, we're talking about kneepoints and ratios and I'll be blunt, most manufacturers today will not let you adjust compression kneepoints because, again, the research, the development, the philosophy of the particular approach to amplification for their individual hearing aids, ratios are usually not directly adjustable but will change based upon on the type of or the amount of gain you're providing to a various level of input. So even though we talk about the benefits of a high kneepoint or a low kneepoint or a high ratio or a low ratio, when you do a fitting with any brand X and you best fit to target X, lot of times those are things that you really can't directly have control over. You're going to need to really understand what each manufacturer's core philosophy in fitting is and know that if you're fitting, again, one brand versus the other, that they have kneepoints that are set a certain way, that generally their ratios are either high or low, and then know their software well enough to deal with troubleshooting of sound quality whether, and it's usually affecting the compression ratio.

And as we move forward and kinda wrap up the session today, I will show you some examples of different fitting formulas and really how it's integrated within the Starkey software, because that's obviously the product I know best, and give you some examples of how we've integrated both kneepoints and ratios into our core fitting philosophy.

Now, the reason I brought that up is really as we move into some of these other characteristics of compression, these are also things that usually in hearing aid fitting software you don't have any control over, but you obviously need to know kind of what the core concept is, what these characteristics are. And one of these are the attack and release time. So essentially an attack time is how quickly does a compression architecture or a compression component respond to an input, and then the release time is how long it takes to come out of compression and go back to kind of the normal amplification or gain of the device. And, again, attack and release times can affect sound quality. So, again, your attack time is how long does it take for a hearing aid to kick into compression, bring the gain down, go into whatever that compression ratio is based upon the intensity of the sound coming in. Then your release time is how long does it take to come back to the quote, unquote normal gain of the device.

Now, with attack and release times, and, again, these are usually built into the compression architecture and every manufacturer has a certain philosophy on attack and release times that they feel work best with their hearing aids or their school of thought. And this is the type of thing that you're going to kinda need to do research on or investigate if you're working with different companies, you know, how does their compression work in terms of their attack and release times, because usually you don't have any control over this. You don't have the ability to go in and change them yourself. So with fast attack times, obviously the benefit is that nothing's gonna get too loud. Whatever sound comes in, it identifies the sound was at or above the point of the kneepoint and needs to go into compression, goes into compression very quickly, basically attacks that sound.

The benefit there is, of course, nothing's gonna get too loud. If it's too fast, a patient can perceive that and it'll seem unnatural. The sound quality will be affected and it just won't sound natural to them to have the sound suddenly being chopped off or brought down very, very abruptly. And when we look at release times, again, it's similar in the sense that if you've got a longer release time it's kind of a gradual release, a gradual return to the typical gain of the hearing aid, that's gonna seem, again, not less abrupt, but if it's too long, the hearing aid might stay in compression to the point where, well, they're missing some information. Maybe they're missing some speech information that's occurring in that time it takes for the hearing aid to come back up to the normal gain or the normal response of the instruments.

So it's a balancing act, if you will, between making sure the attack times are fast enough to react to a sound that might, again, be uncomfortable but not so fast that it changes or distorts the sound quality. And then you want the release time to be long enough that you don't get a kind of a pumping effect where the hearing is turning down, turning up, turning down, turning up, but if it's too long, where they're gonna potentially lose some useful information, 'cause the hearing aid's still compressed. And, again, every manufacturer has kind of their core philosophy on what their attack and release times should be to balance these two things, so both comfort and then natural sound quality, bringing the hearing aid back to normal gain. The volume control, obviously not everyone uses volume controls on their hearing aids anymore or you as a professional may not activate a volume control on the hearing aid because of today's sophisticated multichannel, multi-compression devices. Again, so this is kind of a more basic discussion of how hearing aid components and the volume control interact with each other. I have to say, this is maybe a little less important for the highly sophisticated digital hearing aids you're working with today, but with your basic hearing aid component obviously you've got sound coming in, it's picked up by the microphone, it's amplified, it's sent out through the receiver and then a certain amount of gain is sent to the ear because of the amplification characteristics. With what's known as input compression you've got essentially the compression components, all of that is affected before the volume control. So, again, the sound comes in, the intensity of that sound is detected, then the hearing aid amplifies, it goes through, maybe the volume is turned up or down, it's then sent out through the receiver at a certain intensity, but the compression components, the compression processing occurs before they're turning the volume up or down.

This is what you've got in pretty much every hearing aid you fit today, because basically every hearing aid you fit today, unless you're turning it linear, is using a form of wide dynamic range compression. So the volume control is occurring after the compression takes it, does what it's supposed to do. Your output compression is where the compression occurs after the volume control. And as we kind of, as the name defines, this is usually where your MPO compression kicks in, just kind of that safety valve is kind of how I define output compression. So you've turned the volume up, the patient has turned the volume up at a certain level to hear whatever they want to hear, but some of the sounds are hitting the MPO which ideally should be set just below their point of discomfort. It's gonna then go into compression to make sure that we don't put some things above the patient's point of discomfort, go above their UCLs. So, again, with today's compression architectures, we're really mixing all of these things together.

Again, in today's discussion and on our presentation today, we're kinda putting each one into a box. You've got linear, then you've got compression, and then you've got output compression. Really, in today's hearing aids, you've got all of these things probably in one shape or form working hand in hand because of the sophistication of today's digital devices. So when we're talking about, again, compression limiting, the idea here is that we're never going to send anything above the patient's UCLs. And here we've got some very unique characteristics, we're wanting to use that compression control to make sure we're not running into peak clipping, so we're gonna negate the effects of distortion, et cetera. You're gonna have very high kneepoints for this, because, again, you're gonna set that kneepoint usually just below their UCL, and then you're gonna have a very high compression ratio, because the whole point of compression limiting or output compression limiting is that we're just gonna clamp down on that sound very aggressively so we're not going above the point of discomfort for the patient.

And that brings us into kind of today's common devices, wide dynamic range compression, and then kind of a side effect or the cousin of it is expansion. So the core idea of wide dynamic range compression is to, again, take all of those sounds in the normal hearing world, that normal dynamic range, and squeeze it down into that more reduced or limited dynamic range. So essentially you're getting more gain or more volume, more amplification for softer sounds to make them audible, have them be perceived, be able to understand speech, et cetera, but as you put in louder and louder and louder sounds, you get less and less and less amounts of amplification via the use of compression.

So you ideally have that same kinda growth of loudness between barely audible to too loud or the point of discomfort in that narrow dynamic range, that is the core idea behind wide dynamic range compression. So as you can see in this example, kinda, again, simplified example, you might give 40 dB of gain for a 20 dB input signal, but for an 80 dB input signal, you might only be giving 10 dB of gain, in just a very simple example of how wide dynamic range compression works. Again, just kind of a quick definition of wide dynamic range compression. Again, it's an input compression approach. You typically have low compression kneepoints, 50 dB or lower. There will be a variety of compression ratios, and, again, this typically really depends on the fitting formula slash the manufacturer you're working with and variable attack and release times, again, because of the sophistication of today's technology you've got that ability. Now, kind of the, a side effect, if you will, of wide dynamic range compression is that historically when wide dynamic range compression was first introduced, soft sounds were over amplified, and kind of the, when I talk about soft sounds, I'm talking about kinda low level ambient noise sounds. So, again, I'm gonna date myself when the first WDRC or wide dynamic range compression product came out, which is known as the K-amp, it was this first approach to give different levels of gain based upon the input.

The downside of that particular approach was that if you approached someone sitting in a quiet room, all the low level sounds were cranked up. The hearing aid was doing its job turning up all the soft sounds and would become abnormally loud. So, again, with wide dynamic range compression the goal is to bring the soft sounds up, particularly soft speech, improve that speech understandability or intelligibility for soft speech inputs, but, again, there's the potential for unwanted soft sounds to become over amplified. The tool that essentially solves this problem is what's known as expansion.

So when you've got your patient sitting in a quiet room maybe in the kitchen reading the newspaper in the morning and the refrigerator motor turns on, expansion essentially does not provide gain for sounds below a certain input level. So that refrigerator noise doesn't get cranked up and they sound like there's a truck in their kitchen. So we're not going to provide gain below certain levels. This way you don't have a hearing aid that's over amplifying these unwanted sounds. And it really only is dealing with the softest environmental sounds that the person is around. And particularly making sure that we're not expanding away speech, 'cause obviously we don't want this approach to affect speech inputs as well.

So now if we take a look at our input/output curve, you actually have an area of expansion, so a point at which below a certain input we're not providing any gain. In this example, it's at 35 dB, so no gain is being provided, but once we hit 35, we're gonna provide a greater than linear amplification so that we can really provide some gain for speech. Then if we hit our kneepoint for compression, we go into a now compression up until we hit our output limiting compression. So you can see in today's hearing aids you've got pretty complex processing happening, and, of course, this is gonna happen across various frequencies as well, it's not just one curve for the hearing aid, you're really looking at multiple curves. Now, just a little bit more detail on expansion, again, it's similar in the sense that you have a ratio, but with the expansion ratio you're going to have it actually be instead of one-to-one or 1.1-to-one as you would have in compression, it's going to be point-something to one, because you're really looking at a greater growth of gain in that little area.

So, again, there are certain things to consider. If you have it really low, expansion thresholds, again, that's the point where you're gonna go into, where you're below what you're not going to amplify at all. This is going to be very good in the sense that you're gonna be guaranteed, so to speak, that soft speech is remaining audible, but the problem is you could still run into generating some noise in the hearing aid. If you set the expansion threshold a little too high, then, yes, you're gonna have a quieter hearing aid, but there's the potential to impact the gain for soft speech. So, again, you need to look at this as a balancing act.

Today, the benefit is you don't just have one expansion threshold, you really are looking at a threshold across the entire frequency range. So, again, your expansion ratio is different than the compression ratio in how you look at it. So your compression ratio is going to be, a compression ratio of one is linear, one to one, when you go into compression it's going to be 1.1 or two-to-one or et cetera, whereas your expansion ratio is always going to be between zero and one. So it's actually, it's less than one. So an example here, you'd see an expansion ratio of .4 to one or .7 to one, kind of the steeper that slopes shows you how more aggressive that expansion might be. Again, when it comes to expansion, you typically don't have any control over this, it's built into the architecture of the device.

And I'm just gonna mention very quickly, 'cause I'm gonna start moving a little quicker 'cause I still have quite a bit of information to run through here and we're running down to our hour mark. In the Starkey products, when what we call our quiet algorithm is actually a combination of expansion architecture and what we call our fast-acting noise management or our speech and noise algorithm.

So we're actually doing kinda multiple processing to make sure the hearing aids are as quiet as possible, but from a perspective of how you utilize or program the hearing aids, there's nothing different that you would do in terms of the software, you would just set it more or less aggressively based upon how quiet the patient wants the hearing aids to be. But know that we are doing kind of multiple processing beyond expansion behind the scenes.

So the other thing that when we talk about compression is the idea of channels versus bands, and today people typically kind of use them as if they're the same thing. And really because within modern hearing aids the number of channels and the number of bands are usually overlapping. Not always, but typically they're overlapping. But technically bands is your frequency response, it's the areas in which that you can provide a certain amount of gain for the patient, where you can go in and shape the sound quality. So here's an example of a 16-band instrument, each one of these individual bands you can change how much gain you're providing for that device, or a 20 band instrument or a 24 band instruments. And you can go in and manipulate it. I kind of think of it as a graphic equalizer for the hearing aid, how you can shape the response. Whereas your channels are actually the frequency ranges in which you've got your compression occurring, kneepoints, ratios, and how your advanced algorithms are functioning as well.

So with your advanced algorithms within your channels, you might be looking at multi-channel directionality, binaural processing, classification of noise, classification of speech or music, how are these different advanced algorithms functioning within each individual channel. So they are two distinct things, but, again, in most hearing aids the channels basically overlap with the bands. But do know that they are unique things, channels and bands are two different things even though they tend to overlap. This kind of brings us now into fitting formulas.

Obviously, there are a variety of formulas out there, most manufacturers have their own proprietary formula around their, again, their core philosophy of amplification. Then there are kind of generic formulas, formulas that have been developed by outside research organizations, and for most softwares you can choose which one of these you want to use, the manufacturer's formula or any one of the generic formulas. Again, just as an example within Starkey's Inspire software, you have the option to utilize what we would recommend, our e-STAT or our proprietary formula or any of the generic formulas, excuse me. NAL-R is your linear formula.

So this is gonna use those, no compression in there until you get up to the output compression limiting. And, again, here's kind of an example of it in our software. You've got your NAL-R, you've got your responses. And I know it's a little tough to see, but here you can see that the compression ratios are all one-to-one, because that's what linearity is. Then you've got your NAL-NL1, so this is kind of the next generation of the NAL formulas into their first compression approach. And, again, in this software, this is using the same audiogram, now you see how we've got some compression being introduced.

You can see ratios of 1.5, 1.8, 1.9, depending on the frequency and the intensity you're looking at. Then NAL Labs developed their second compression or non-linear approach, which they call NL2. And now you can see the NL2 formula. You can see their response for the same audiogram. Much more compressed. And you can see that visually with how the curves are closer to each other, but, again, now down in the lower half of the graph you can see 2.6 ratio, 1.8, 2.4. And then you've got DSL version five. This is typically utilized for pediatric fittings, that's what it was specifically designed for, and you can, again, see the difference in its response in our software and its ratios kind of in these gray bars here.

But that gives you a little bit of an idea of kind of the differences between the generic formulas. Now, our specific e-STAT or evidence-based statistical analysis formula, again, is designed specifically around our core philosophy, which is to maximize audibility for speech understanding. At its core, we have low compression ratios, we have low kneepoints, it's a fast-acting, pretty fast attack and release times, and the advantage of having a proprietary formula is that we can update it as we get more and more information, and we do regularly update it. We have hit the hour mark. I'm gonna be honest with you, I probably have about another 10 minutes, so I'll try and get through this as quickly as possible. But here's a quick comparison across all of the generic or public formulas and e-STAT. If you want, a lot of people say, what's e-STAT closest to? And I always say, well, it's kind of as if NAL-R and NL1 had a baby, that's kind of it's best description.

From a frequency shaping perspective, it's closer to NAL-R. From a compression perspective, it's closest to NL1. And that's really where we get into, again, to our approach to compression, what we call our independent speech optimization. Sometimes you'll hear it referred as acuity speech. This is really just our form of wide dynamic range compression. And with it, again, our goal is maximizing audibility for speech, so what we do is we base our kneepoints on the long-term average speech spectrum, or the LTASS for soft and moderate speech inputs. So a 50 dB speech input and a 65 dB SPL speech input. Across the frequency response we've measured the average speech, the input, the average intensity of speech from the lowest frequency out to our highest frequency, and that's where we've set our kneepoints. And then we do that for a 50 dB speech input, we do that for a 65 dB speech input and set our kneepoints for those two compression regions. And then, again, generally you'll see us have relatively low ratios because we believe that provides the best sound quality. We're not going to run into that muffled or mushy sound quality. And this is what defines the Starkey sound quality is this particular approach to wide dynamic range compression.

And, again, in the software, this is the same audiogram that we looked at for all the other fitting formulas, I think this was like a flat 50 dB hearing loss. You can see that our kneepoints are typically going to be in these ranges, 1.3 to maybe 1.7. It's very rare with e-STAT to see a compression ratio go above two-to-one. And, again, that just comes down to our core philosophy of fitting. Now I'm gonna wrap up with just a discussion of speech versus music, because a music input is very different from speech. So everything that we just talked about with our compression architecture, our fitting formula, and compression in general, wide dynamic range compression in general has been all focused in on speech. Music is very, very different, which is why within Starkey devices we actually have a completely second, separate twin compressor for a dedicated music memory.

So with that particular memory, if you select as one of the patient's memories in their hearing aids, our dedicated music memory, we actually completely switch our compression approach. It is not using any of the formulas we've just talked about, we have a unique propriety music formula, all of the kneepoints and ratios are different, essentially the dynamic range is treated differently for music than it is for speech because they're completely different types of sounds and patients want a different sound quality for music than they do for speech. So this is a very very good music approach.

Historically, music has been very poorly processed through hearing aids, because that's not really what hearing aids have been designed for. But with our dedicated, unique music compression and memory, it's really providing fantastic sound quality whether they're listening to music, playing music, singing in the church choir, et cetera. And the other thing is you would deal with it differently in the software, and this is an example of that where if you've got a music memory, you're really no longer looking at input/output curves or SPL curves or gain curves or the way you typically look at a hearing aid response.

You're looking at it from, again, what I tend to refer to as a graphic equalizer approach with bass, mid, and treble in terms of adjusting what type of musical input or sound that they need more or less of. And you can even break that down into individual channels for the music in terms of soft and loud as well. So that's just kind of an aside when it comes to compression because your wide dynamic range compression approaches, whether it's our e-STAT or other proprietary formulas or the generic public formulas don't deal with music, they're not designed to deal with music, that's why our secondary or twin compression approach with specific dedicated music compression really provides the best music sound quality that you can offer to your patient.

Now, we've gone through a lot of concepts, and really one of the big things to take away from this is that not everyone is going to want the same approach, that's the benefit of today's digital hearing aids. It's not like it used to be when I started fitting where you had, again, a single-channel device, you maybe had a trem pot that could change the kneepoint, and that was it, maybe change the MPO compression, and that was it. Today, you can combine linearity with WDRC, with MPO, with the dedicated music compression, et cetera. And it's because everyone's auditory system is different and reacts differently to amplification. Linear doesn't work for everybody, obviously, but neither does pure WDRC.

Not everyone's gonna want to use the same formula. If you're working with Starkey, we would say start with e-STAT. But there will be a small percentage of people who e-STAT won't be appropriate for and you're going to have to experiment maybe with an NL2 or an NL1, and an NAL-R if they're a linear user. People have their own preferences for sound quality, dynamic range changes from person to person. But the advantage of today's digital products is that you can combine all of this along with the advanced signal processing of noise management, et cetera, to really get the patient as happy as they possibly can be and hearing as best as the possibly can.

So I want to thank everyone who stuck with me, I've gone seven minutes over, I want to apologize for that. If you've got any questions, feel free to ask them. If you need to log off and get back to work, I understand that as well. So I want to thank everyone for joining me. I'll stay on for a few minutes and see if we have any questions, and, again, if not, if you need to log off, feel free to do that, and hopefully we'll see you here at Audiology Online in the future. And I'll just hang around for a few moments and see if I get any questions.