Effects of dynamic range compression on spatial selective auditory attention in normal-hearing listeners

Harvard/Massachusetts Institute of Technology, Speech and Hearing Bioscience and Technology Program, Cambridge, Massachusetts 02139

Center for Computational Neuroscience and Neural Technology and Biomedical Engineering, Boston University, Boston, Massachusetts 02215

(Received 5 October 2012; revised 13 February 2013; accepted 14 February 2013)

Many hearing aids introduce compressive gain to accommodate the reduced dynamic range that often accompanies hearing loss. However, natural sounds produce complicated temporal dynamics in hearing aid compression, as gain is driven by whichever source dominates at a given moment. Moreover, independent compression at the two ears can introduce fluctuations in interaural level differences (ILDs) important for spatial perception. While independent compression can interfere with spatial perception of sound, it does not always interfere with localization accuracy or speech identification. Here, normal-hearing listeners reported a target message played simultaneously with two spatially separated masker messages. We measured the amount of spatial separation required between the target and maskers for subjects to perform at threshold in this task. Fast, syllabic compression that was independent at the two ears increased the required spatial separation, but linking the compressors to provide identical gain to both ears (preserving ILDs) restored much of the deficit caused by fast, independent compression. Effects were less clear for slower compression. Percent-correct performance was lower with independent compression, but only for small spatial separations. These results may help explain differences in previous reports of the effect of compression on spatial perception of sound.

[http://dx.doi.org/10.1121/1.4794386]

PACS number(s): 43.66.Ts, 43.66.Pn, 43.66.Dc [MAS] Pages: 2329–2339

Dynamic range compression is routinely used in hearing aids to address the limited dynamic range available to hearing-impaired listeners (Moore, 2007). Such compression generally improves audibility and speech intelligibility (Moore, 1996; Jenstad *et al.*, 1999). However, when applied independently to both ears, dynamic range compression can alter interaural level differences (ILDs), which provide important information about acoustic source location (Byrne and Noble, 1998). It is not clear, however, how such alterations in ILDs influence spatial auditory perception. Compression has little effect on the ability of either normal-hearing or hearing-impaired listeners to accurately localize sounds presented in isolation (Keidser *et al.*, 2006; Musa-Shufani and Walger, 2006). Yet compression can degrade the ability to discriminate small differences in ILD (Musa-
,andcannormal-hearing

Spatial acoustic cues such as ILD can be particularly helpful in allowing listeners to attend to and understand a desired sound source when multiple competing sources are present (e.g., Shinn-Cunningham, 2005, 2008; Shinn-Cunningham and Best, 2008). The term “spatial selective auditory attention” refers to cases in which listeners specifically use spatial cues to focus on a desired sound source and mediate competition from distracting sources from other locations (e.g., Ruggles and Shinn-Cunningham, 2011). Spatial separa-

therefore, the overall stimulus level was roughly equivalent regardless of the compression condition.

In both Experiments 1 and 2, we used three compression conditions: linear processing, independent compression, and linked compression. For linear processing, the same multiband compressor algorithm was used as in the other conditions, but with the compression ratio set to 1:1 (ensuring that any effects we observed were not due to the multiband analysis/resynthesis, but due to the compression). For linked compression, in any given 8-ms time window, the gain applied to both the left and right ear signals in a particular frequency band equaled the minimum of the gains that would have been applied to the two signals when the compression was independent. The linked compression condition therefore had a slightly lower binaural level than the independent compression condition; whenever a non-zero ILD was present in a compression band, the ear with the less intense signal received less gain in the linked compression condition compared to in the independent compression condition. In Experiment 1, the "Fast" condition used attack and release times of 11 and 82 ms, respectively (ANSI, 2003), and the "Slow" condition used attack and release times of 48 and 730 ms, respectively. Experiment 2 used only the fast attack and release times. In all cases, the compression scheme estimated power within each band using 8-ms time windows, then smoothed this power estimate to produce the appropriate attack and release time constants before determining the amount of gain to apply.

[illegible]

We designed an adaptive procedure to estimate subjects' spatial threshold, defined as the separation needed between target and maskers to obtain threshold-level performance. Specifically, the lateral position of the symmetrically placed maskers was adaptively varied until the percentage of target digits correctly reported reached threshold. In Experiment 1, the adaptive procedure tracked 67% correct using a weighted up-down procedure (Kaernbach, 1991): the masker position was decreased by 5° after each correct response and increased by 10° after each incorrect response. In Experiment 2, the 50%-correct threshold was found using a 1-up 1-down procedure (Levitt, 1971). Note that in Experiment 2, the BRIRs were not spaced evenly throughout the azimuthal plane. Therefore, the adaptive track increased or decreased the lateral positions of the maskers by one azimuthal sample (5° for sources near midline; 10° for more lateral locations). In both experiments, an adaptive run continued until 12 reversals were recRual s percent-correct scores, but have more uniform variance than percent-correct scores.

Subjects were instructed to type in the four digits spoken by the target talker coming from center, using the midline cue spatial thresholds greater than 25°. These values suggest that ceiling effects may limit the observable differences in spatial thresholds across compression conditions in Experiment 2.

Figure 2 plots within-subject differences in spatial thresholds relative to the spatial threshold in the independent condition (which we hypothesized would be largest, due to ILD fluctuations and image diffuseness). For all groups using fast compression (Fast condition in Experiment 1 and all three conditions in Experiment 2), subjects tended to perform worse with independent compression than for either linear processing or linked compression. This produced negative spatial threshold differences in Fig. 2, consistent with our hypothesis. These differences were small, generally under 10°. Because little is known about the distribution of spatial thresholds across subjects, we used a directional

Moreover, each individual subject made significantly more
switch errors than would be expectv aatha(a)b9.7(o)0(h)-4r7hbrp02ddedd.(h)01.3(6)01hoi9TD[s mo4672(l67.3(s)l7(c30515.69TD[

processing or linked compression only when target and maskers were separated by a small angular separation (15°). Independent compression did not affect performance for large azimuthal separations (90°). We suggest that increased image width and diffuseness caused by independent compression (Wiggins and Seeber, 2012) only affect spatial selective attention if competing sources are sufficiently close to each other in azimuth such that these effects cause confusion about whether a particular sound is from the target or a masker. A more thorough analysis of the acoustic effects of compression on the spatial cues available to normal-hearing and hearing-impaired listeners can lend further insight into this idea, and is one focus of our future research.

Differences across the compression conditions were driven by switch errors, in which subjects selected one of the masker digits, further supporting the idea that compression interfered primarily with source selection rather than with speech intelligibility. Similar results can occur even in diotic mixtures (increased "reversals"; Stone *et al*., 2009), indicating that overall cognitive load, and not necessarily spatial factors, may also contribute to our results. In considering this possibility, it is important to note that the previous study that found increased reversals for diotic mixtures used a cognitively demanding task in which subjects divided attention listeners (Wiggins and Seeber, 2011, 2012). It is reasonable to suspect then that the dynamics of hearing aid compression may have deleterious effects on the ability of hearing aid wearers to use spatial cues to attend to a desired sound source. Further research with hearing-impaired listeners, using a more representative range of compression settings, can help clarify the practical consequences of the effects being explored here.

In our experiment, we chose to place maskers symmetrically about midline. In retrospect, this choice may have led us to underestimate the possible size of effects. We found that performance was impaired when the maskers were close (15°) to the target, but not when they were far (90°). For close maskers, the magnitude of ILDs in the acoustic mixtureagnitude of ILDs in th

Marrone, N., Mason, C. R., and Kidd, G. (**2008b**). “The effects of hearing