Original Article

Air Traffic Controllers' Long-Term Speech-in-Noise Training Effects: A Control Group Study

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Abstract

Introduction: Speech perception in noise relies on the capacity of the auditory system to process complex sounds using sensory and cognitive skills. The possibility that these can be trained during adulthood is of special interest in auditory disorders, where speech in noise perception becomes compromised. Air traffic controllers (ATC) are constantly exposed to radio communication, a situation that seems to produce auditory learning. The objective of this study has been to quantify this effect. **Subjects and Methods:** 19 ATC and 19 normal hearing individuals underwent a speech in noise test with three signal to noise ratios: 5, 0 and −5 dB. Noise and speech were presented through two different loudspeakers in azimuth position. Speech tokes were presented at 65 dB SPL, while white noise files were at 60, 65 and 70 dB respectively. **Results:** Air traffic controllers outperform the control group in all conditions [$P<0.05$ in ANOVA and Mann-Whitney U tests]. Group differences were largest in the most difficult condition, SNR=−5 dB. However, no correlation between experience and performance were found for any of the conditions tested. The reason might be that ceiling performance is achieved much faster than the minimum experience time recorded, 5 years, although intrinsic cognitive abilities cannot be disregarded. **Discussion:** ATC demonstrated enhanced ability to hear speech in challenging listening environments. This study provides evidence that long-term auditory training is indeed useful in achieving better speech-in-noise understanding even in adverse conditions, although good cognitive qualities are likely to be a basic requirement for this training to be effective. **Conclusion:** Our results show that ATC outperform the control group in all conditions. Thus, this study provides evidence that long-term auditory training is indeed useful in achieving better speech-in-noise understanding even in adverse conditions.

Keywords: Air Traffic Controllers, auditory training, psychoacoustics, speech perception in noise

Introduction

The ability to understand speech perception in noise requires both sensory and cognitive skills.[1] The sensory part consists of the auditory system locking on to the target speech signal while excluding competing voices and ambient noise. This is achieved by organizing auditory inputs into different groups by identifying shared characteristics, such as location and acoustical similarity. The identity of these groups is given by the relative stability of voice pitch and helps in grouping it separately from other voices. In addition, other signal-based cues like timing, harmonics, and location aid in group formation of speech. On the cognitive side, attention and working memory skills are the key to a good speech-in-noise (SIN) ability.[2-4]

There is evidence that such skills can be improved during an adult's life, causing perceptual enhancements and plasticity in single neurons and in neuronal populations.[5,6] Studies of auditory perceptual learning reveal long-term neural changes in the adult auditory cortex of both animals and humans after intensive auditory training.[7,8] Current models propose that perceptual learning in adults depends strongly on top–down influences such as attention, reward, and task relevance. This demonstrates that the adult auditory cortex is a dynamic and

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adaptive processing center.[9-18] In humans, learning-related cortical plasticity has been found after discrimination training using tones[19] and synthetic speech stimuli.[20,21] However, there have been far less investigations of how training impacts SIN perception.[22-24] The studies used small stimulus sets and indicate that SIN perception can improve when training in artificial listening conditions, but that generalization to untrained materials is limited. These findings suggest that learning resulting from such training paradigms is specific to the trained speech materials and the parameters of the background noise: signal-to-noise ratio (SNR), noise spectra, etc. Nevertheless, musical training has been shown to improve speech perception under challenging conditions.[25] This study by Parbery-Clark *et al.*[25] examined subcortical encoding of the same speech syllable presented in predictable and variable conditions and SIN perception in musicians and non-musicians. Musicians showed enhanced speech perception in background noise. They demonstrated greater neural sensitivity to regularities in ongoing speech. This neural sensitivity correlates with SIN perception. The study offered the first empirical evidence that naturalistic training can enhance how the nervous system encodes acoustic cues that are important for understanding speech in noise.

Another, unexplored, environment where natural auditory training occurs is in job sectors with frequent radio communications. This is the case of Air Traffic Controllers (ATC). People who work in this field are constantly exposed to degraded SIN, which is extremely hard to understand to an outsider. The entering requirement for ATC in Spain regarding audition is a simple tonal audiometry. They need to have hearing thresholds below 20 dB HL for frequencies from 0.5 to 8 kHz. In addition, they must pass a psycho-technical test where their cognitive skills are evaluated (known factors that helps SIN understanding). However, they all report being unable to understand radio conversations at first. During their working life, ATC learn to identify, extract, and comprehend conversations embedded in white noise. These conversations are normally restricted to the aeronautics field, which makes them an ideal population to study the effects and transferability of long-term auditory training. This population sector has never been studied regarding their SIN abilities.

As opposed to previous work where the subjects are trained *in situ* and then tested, the aim of this study is to clarify the extent to which someone's "real world" listening experience achieved by their occupation can lead to enhanced performance on a laboratory-based test. The main objective of this study has therefore been to evaluate whether ATC's long-term auditory training has equipped them with better SIN perception. In this study, we aim to advance our understanding of experience-dependent plasticity, in accordance with the theoretical framework in which subcortical and cortical structures work in a cohesive manner to enable complex auditory learning.[26-28] By showing that natural training can improve how the adult nervous system processes speech in noise, these results promote the possibility of improving a fundamental, yet challenging, aspect of human communication in a wide range of populations.

Subjects and Methods

This observational study was done at the Air Base of Gando Airport of Gran Canaria and the Psychoacoustics Laboratory of the Hearing Loss Unit, Otolaryngology Head and Neck Department, Complejo Hospitalario Universitario Insular Materno Infantil de Gran Canaria (CHUIMI). The Ethical Committee of the CHUIMI approved this study and subjects gave their informed consent before the commencement of the test.

Subjects

19 ATC and 19 normal-hearing subjects were selected as control group and target group respectively, aged 23–54 years (mean age of ATC group = 41 years, SD = 3.49; mean age of the control group = 37 years, SD = 13.49). All subjects were native speakers of Spanish language. The subjects had normal hearing with pure tone thresholds better than 20 dB HL as measured by a validated clinical audiometry (from 0.5 to 8 kHz) and with no other known pathology. None of them had prior experience with acoustic simulations or had participated in any hearing research experiment. All subjects came voluntarily and gave informed consent. The control group was searched so as to match the ATC group in age and audiometric results as closely as possible. This fact accounts for the larger SD in the control group, because it was harder to find control subjects older than 40 with pure tone hearing thresholds better than 20 dB HL. In the control group, the occupations were: teachers, university professors, university students, doctors, nurses, cleaning ladies, and researchers.

Speech material and background noise

The Spanish disyllabic speech test from the protocol for the assessment of hearing in Spanish Language was used to study the effect of training in SIN perception.[29] Three validated lists of 25 disyllabic words each were used, spoken by a female speaker with Spanish accent from Spain [Table 1]. This test has been designed to have a balanced number of phonemes in each list, and the same numbers of common and uncommon words, to ensure that all lists are equally difficult. The lists were played at a fixed sound level of 65 dB SPL. A white noise file was generated, sampled at 44.1 kHz and each one of the lists was assigned a noise file. This way, three sets of SNR conditions were created: +5 dB, 0 dB and −5 dB.

Procedures

During the experiment, the listener was seated 1 m away from two loudspeakers (one played the noise file and the other the background noise), Samson Resolv A5 (Samson Technologies, Haupauge, New York, United States). The loudspeakers were placed in azimuth 0° position to the

Table 1: Word content of each list*

+5 SNR	0 SNR	–5 SNR
alga	rubios	clase
lunes	cuatro	fuera
tiendo	urna	litro
bondad	guías	paran
choca	tío	sello
dejo	amor	unos
humo	cierta	vienen
mero	filo	hielo
pila	lejos	basta
sueño	fundes	crean
borde	santa	gente
terca	anchos	paso
nubes	pecho	sola
brisa	actor	viñas
cinco	Hábil	renta
hijas	tiendas	idas
justa	padre	pegues
mesa	papel	duque
pintor	saco	medios
fuente	madre	mimas
ese	una	coger
hacha	conde	hotel
leyes	cine	techo
torres	ese	alzar
alzar	leyes	dice

*They were extracted from the Spanish disyllabic speech test for the assessment of hearing loss. The conditions under which each one was applied are specified in their respective headings

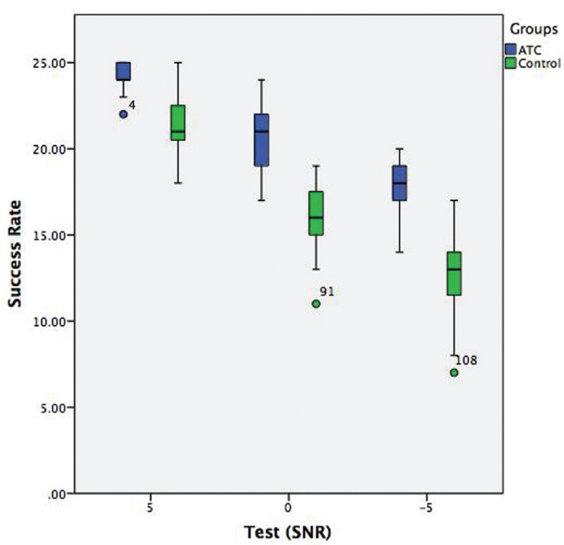

Figure 1: Success rate of ATC and control groups as a function of test. The ATC group outperforms the control group in all SNR conditions and the difference between them becomes larger as noise increases

subject. The experiment took place in a quiet room (3 m × 3 m), with a background level below 30 dB(A). Sound was produced using the acoustic card of a MacBook Pro, Core i5 Intel double core 2.4 GHz computer (Apple Inc., Cupertino, California, United States) using Audacity v2.0.5 software (Audacity Computer software audio editor http://audacity.sourceforge.net/).[30] Each listener was presented to the lists without prior practice time. All subjects listened to three lists plus noise as described in the previous section.

The sound pressure level of the lists was calibrated to be 65 dB-A using a sound-meter. To limit possible learning effects, the lists were presented from easiest to most difficult SNR condition.

Statistical analysis

IBM SPSS Statistics, Version 21.0 was used for the statistical analysis (Armonk, NY: IBM Corp.). The variables under study were: the results of each SNR test (dependent variables), the years of experience in the job, and the age (both independent variables). The statistical analysis started with a normality check for each specific SNR condition using Kolmogorov–Smirnov test for one sample. According to the result, an analysis of variance (ANOVA) or a Mann–Whitney *U* test was applied to search for significant differences between the two groups. Finally, correlations between age, years of experience in the aeronautic field and test scores were analyzed using a Pearson correlation test. $P \leq 0.05$ was chosen as the level of significance.

Results

First, a normality check for each list was done, to ensure the use of the correct statistical test. All lists satisfied this condition for the control group. Both SNR = 0 and −5 dB ATC lists followed Gaussian distributions, but SNR = 5 dB did not. This could be due to ceiling effects, since all subjects obtained scores of either 24/25 or 25/25 (mean = 24.474; SD = 0.51).

Then, to determine if training-related changes in performance were statistically significant, ATC performance scores were compared with scores obtained from the control group for each SNR condition. An ANOVA and a Mann–Whitney *U* test (for the case SNR = 5 dB), revealed performance differences between the two groups in all cases. Figure 1 shows how the difference between them gets larger as noise increases. The evaluation of significance returned *P*-values < 0.05 for all cases, thus revealing significant differences between the two groups. For SNR = 5 dB, the Mann–Whitney *U* test gave a $P = 0.000$. For SNR = 0 dB, ANOVA test gave $F = 42.136$; $P = 0.000$. Finally, for SNR = −5 dB, $F = 68.456$, and $P = 0.000$. The difference in mean between groups is 12.84% for SNR = 5 dB (control mean = 21.263; ATC mean = 24.474); 16.84% for SNR = 0 dB (control mean = 16.105; ATC mean = 20.316) and 21.90% for SNR = −5 dB.

The plots of working experience and age with results for each condition are shown in Figures 2 and 3, respectively. No significant correlation was found between either of these variables according to the Pearson correlation tests

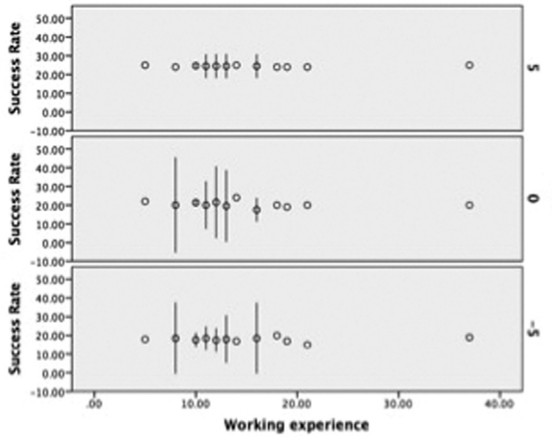

Figure 2: Success rate as a function of working experience. They seem to follow a flat, constant line, indicating a possible ceiling effect. No significant correlation was found between the two variables

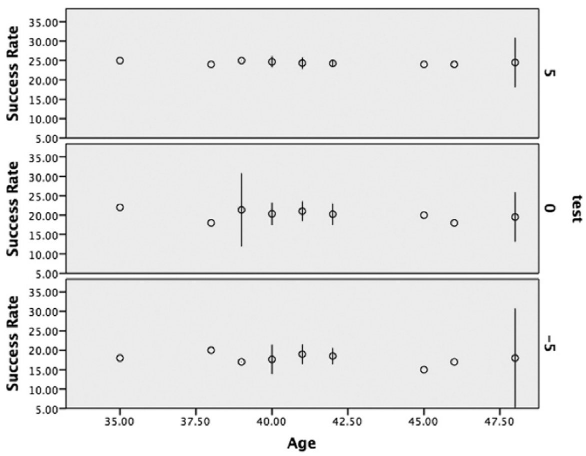

Figure 3: *Success rate as a function of age. The first seems to be constant across the x-axis. No significant correlation has been found for these two variables*

performed. Test results were as follows: for SNR = 5 dB, $R = 0.046$ and $P = 0.851$; for SNR = 0 dB, $R = -0.231$ and $P = 0.340$; for SNR = –5 dB, $R = 0.023$ and $P = 0.927$.

Discussion

This study is the first to indicate that the biological mechanisms responsible for speech perception in noise can be altered with long-term training, and that the benefits of training are maintained over time. Training-induced brainstem plasticity is not a new concept, but unlike previous studies, we shifted the paradigm and, instead of training subjects in an artificial setting, we recruited already trained subjects in real-world listening situations to evaluate whether they have gained measurable benefits in a laboratory test.[30-32] By showing that a general training approach can affect speech perception in noise, we provide an important conceptual advance to our understanding of the kind of training experiences that can influence sensory processing in adulthood.

Song *et al.* studied training-related malleability using a program that incorporated cognitively based listening exercises to improve SIN perception.[33] Trained subjects exhibited significant improvements in SIN perception that were retained 6 months later. Subcortical responses in noise demonstrated training-related enhancements in the encoding of pitch-related cues. This was the first demonstration that short-term training can improve the neural representation of cues important for SIN perception. More recently, Sweetow and Henderson-Sabes[34] prospectively assessed the generalization of SIN training in a cohort of individuals with hearing loss. Whitton *et al.*[35] prospectively assessed the effect of signal-in-noise, audio-game training on speech understanding in noise with untrained materials. On the other hand, Fu and Galvin[36] and Moore and Shannon[37] have shown that targeted auditory training can enhance performance gains provided by new implant devices and/or speech processing strategies. These results provide a conceptual advance to our understanding of the kind of training experiences that can influence sensory processing in adulthood.

These findings and those from the present study suggest new therapeutic options for clinical populations that receive little benefit from conventional sensory rehabilitation strategies.

However, the only groups that have been studied that have had some sort of long-term training are musicians, who are auditory experts. For example, Parbery-Clark *et al.*[25] investigated the effect of musical training on SIN performance. They found that musical experience appears to enhance the ability to hear speech in challenging listening environments. The results also suggest that this enhancement is derived in part from musicians' enhanced working memory and frequency discrimination.[38]

We argue that changes in perception and neurophysiology likely resulted from the way in which ATC's training integrates cognitive factors (the effort put into understanding the words being said in radio communications for the correct operation of their station) into their natural auditory training exercises. This kind of approach is ideal for improving the ability to listen in noise because sensory and cognitive processes must operate in tandem to extract and decode the target signal. Thus, by invoking high cognitive demands (technical sentences, auditory working memory, attention, and stress upon understanding the messages correctly), their daily activities may strengthen cortical processes, which in turn improve sensory awareness when listening to SIN. This explanation is consistent with a theoretical framework of subcortical plasticity in which the brainstem operates as part of an integrated network of subcortical and cortical structures linked by afferent and efferent processes.[26,28] In this theoretical framework, brainstem activity can both "influence" and "be influenced by" cortical processes. Here, we provide evidence that this network is subjective to training, by showing that improved SIN performance was obtained by those with extensive training.

The results in this study indicate that ATC, just like musicians, are more capable of identifying SIN. This ability is most apparent in the most adverse case, when the signal is lower than the noise. In all cases, they obtained better scores than the control group. Even though the set of words used were completely unknown to them, it seems that the skills learnt in one particular auditory situation are transferable to a new and different one, in this case, the laboratory test. This is an interesting result, since the first thing that subjects commented after being informed of the purpose of the study was that they "would probably not perform better because their 'trick' is that they know which words to expect during radio communications." However, it is clear from the results that this is not the case and they could identify more words than the standard population. It is likely that the ATC are more adept at focusing on acoustic speech cues which may be less degraded by the presence of background noise, requiring a lower time of adaptation and therefore missing less information.

However, no significant correlations between years working and age were found. The studies afore mentioned suggest that training improvements develop after a short period of time. Thus, it is possible that the learning curve is steeper during their first year of training and approaches a plateau thereafter. Another reason might be the intrinsic cognitive abilities of this population to identify speech in noise. Further studies where brain activity is monitored can be a very interesting continuation of the present one. Also, following ATC during their initial training year might also yield a correlation between time spent using radio communications and SIN perception.

Our aging society is bound to suffer SIN understanding impairments. As individuals grow older, this ability degrades even before auditory losses become clinically relevant. Therefore, it is crucial to come up with strategies to try and slow this process down as much as possible. Given the recent proofs that learning during adulthood is far greater than previously thought, the demonstration that auditory training under degraded sound quality can lead to better SIN understanding can have big implications in the way hearing loss is treated today. Hence, research in the line of this study will certainly aid in the development of efficient and effective training protocols and materials.

Conclusion

Accurate speech perception in noise relies on the capacity of the auditory system to process complex sounds in the presence of background noise using both sensory and cognitive skills. There is evidence that these can be enhanced during an adult's life, leading to long-term neural changes in the adult auditory cortex. This shows that the auditory cortex is a dynamic and adaptive processing center.

Unfortunately, available literature has only focused on short-term training with restricted speech material or musicians. However, there are other populations sectors that benefit from a natural auditory training environment, due to constant and demanding radio communications. This is the case of ATC. This study shows how this sector has better SIN perception than the standard population.

The implications of these findings can result in better rehabilitation therapies for people with hearing loss, since it seems that at least in normal hearing individuals, the daily exposure to SIN can result in adaptation and enhanced performance, although more work should be done to characterize the learning curve before jumping into further conclusions.

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Conflicts of interest

There are no conflicts of interest.

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