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Original Article

# Effects of Long-Term Speech-in-Noise Training in Air Traffic Controllers and High Frequency Suppression. A Control Group Study

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**OBJECTIVE:** To evaluate 1) if air traffic controllers (ATC) perform better than non-air traffic controllers in an open-set speech-in-noise test because of their experience with radio communications, and 2) if high-frequency information (>8000 Hz) substantially improves speech-in-noise perception across populations.

**MATERIALS and METHODS:** The control group comprised 28 normal-hearing subjects, and the target group comprised 48 ATCs aged between 19 and 55 years who were native Spanish speakers. The hearing -in-noise abilities of the two groups were characterized under two signal conditions: 1) speech tokens and white noise sampled at 44.1 kHz (unfiltered condition) and 2) speech tokens plus white noise, each passed through a 4th order Butterworth filter with 70 and 8000 Hz low and high cutoffs (filtered condition). These tests were performed at signal-to-noise ratios of +5, 0, and −5-dB SNR.

**RESULTS:** The ATCs outperformed the control group in all conditions. The differences were statistically significant in all cases, and the largest difference was observed under the most difficult conditions (−5 dB SNR). Overall, scores were higher when high-frequency components were not suppressed for both groups, although statistically significant differences were not observed for the control group at 0 dB SNR.

**CONCLUSION:** The results indicate that ATCs are more capable of identifying speech in noise. This may be due to the effect of their training. On the other hand, performance seems to decrease when the high frequency components of speech are removed, regardless of training.

**KEYWORDS:** Speech-in-noise perception, psychoacoustics, auditory training, air traffic controllers

## INTRODUCTION

The ability to understand speech 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 ambient noise and competing voices. This is achieved by organizing auditory inputs into different groups by identifying shared characteristics such as location and acoustical similarity. The identification of these groups is given by the relative stability of voice pitch, which helps in grouping a voice separately from other voices. In addition, other signal-based cues, such as harmonics, location, and timing, aid in group formation of speech. On the cognitive side, attention and working memory skills are key to good speech-in-noise (SIN) abilities [2-4].

There is evidence that such skills can be improved during an adult's life, causing perceptual enhancements and plasticity in single neurons as well as in neural populations [5, 6]. Studies of auditory perceptual learning reveal long-term neural changes in the adult auditory cortex (AC) 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 AC is a dynamic and adaptive processing center [9-18].

Natural auditory training occurs in job sectors involving frequent daily radio communications. This is the case for air traffic controllers (ATCs). People who work in this field are constantly exposed to SIN, which is extremely hard to understand to an outsider. During their working life, ATCs learn to identify, extract, and comprehend conversations embedded in white noise. These conversations are normally restricted to the aeronautics field, which makes ATCs an ideal population, in whom the effects and transferability of long-term auditory training can be studied.

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Unfortunately, the majority of studies on how training affects SIN perception used small stimulus sets and revealed that while SIN perception can improve in artificial listening conditions, the benefit for untrained materials is not clear [19-22]. As opposed to previous studies, in which the patients were trained in situ and then tested, the aim of this study is to clarify the extent to which an individual's "real world" listening experience gained because of their occupation can lead to enhanced performance on a laboratory-based test. The main objective of this study is to demonstrate that the long-term auditory training of ATCs has equipped them with better SIN perception. Moreover, the role of high frequencies has also been evaluated because radio communications are limited to 8 kHz, as with hearing prosthetics. Thus, the second aim of the study is to investigate how ATCs performed in a SIN test when frequencies above 8 kHz were filtered out compared with the performance of the general population.

## MATERIALS and METHODS

The Ethical Committee of our center approved this study, and patients gave their informed consent prior to the commencement of the study.

### Subjects

Twenty-nine normal-hearing subjects (aged 19–55 years) from a previous study were included in the control group and 48 ATCs (aged 34–56 years) were included in the target group 23. All subjects were native speakers of the Spanish language. The subjects had normal hearing (NH) with pure tone thresholds better than 20 dB HL, as measured by validated clinical audiometry (from 0.5 to 8 kHz in steps of 0.5 kHz) and with no other known pathology. None of the subjects had previously taken part in any auditory experiments, and they all signed an informed consent form before commencement of the study.

The recruiting process yielded different group sizes. This is because the announcement for normal-hearing subjects was made within the hospital and the university. In the second group, the head of Risk Management Department sent an email informing the ATC community. Because they are accustomed to doing surveys and participating in humanitarian activities, such as blood donation, their cooperation was much higher.

Age histograms for the ATC and control groups are illustrated in Figures 1 and 2, and the number of years spent working in the sector for the ATCs are illustrated in Figure 3.

### Speech Material and Background Noise

The methods used in this study are analogous to those published by the authors in a previous article and therefore will only be outlined here [23].

The Spanish disyllabic speech test was modified to study the effects of training and high-frequency suppression on SIN understanding. Six validated lists of 25 words each were used. Frequency altered words and noise files were generated using MATLAB and Statistics Toolbox Release 2012b (The MathWorks, Inc; Natick, MA, USA). The lists were split into two groups of three lists each. In the first group, the frequency components were unaltered, with a maximum sound frequency of 22 kHz; in the second group, the words were band-pass filtered using a Butterworth filter of 4th order with a band pass from

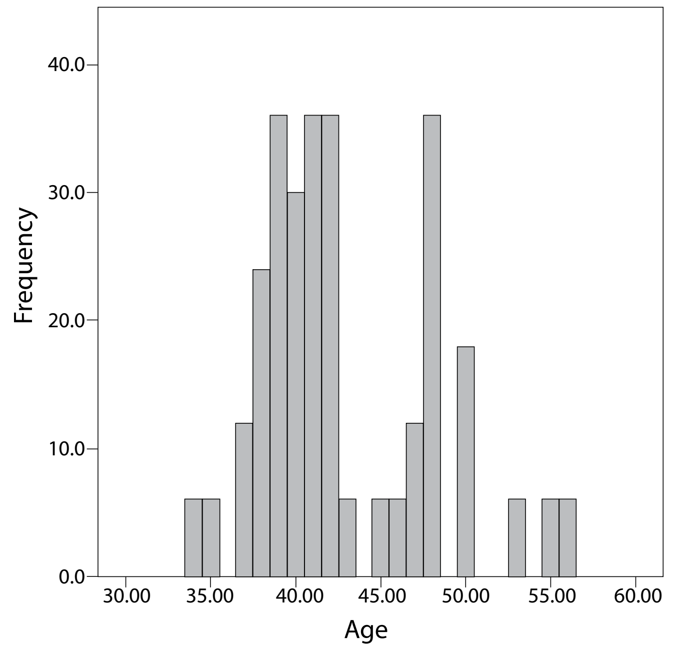


**Figure 1.** Age distribution of ATC group

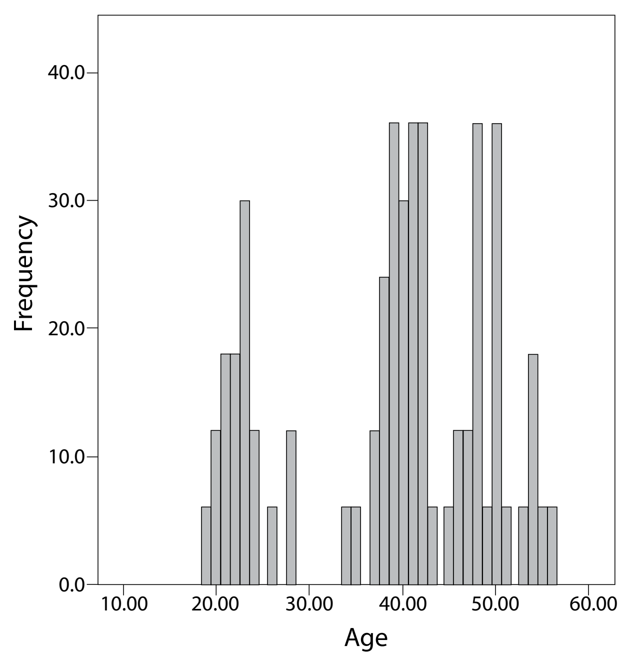


**Figure 2.** Age distribution of control group

70 Hz to 8 kHz. For future reference, these groups will be referred to as groups A and B, respectively.

Two white noise files were also produced. The file corresponding to group A was sampled at 44.1 kHz, and the second was obtained by passing the first file through the same filter used for group B. Varying the intensity of these two files, three sets of SPLs were tested: SNR +5 dB (noise at 60 dB); 0 dB (noise at 65 dB), and −5 dB (noise at 70 dB).

The subjects thus listened to a total of six lists at 65 dB SPL, three from each list.

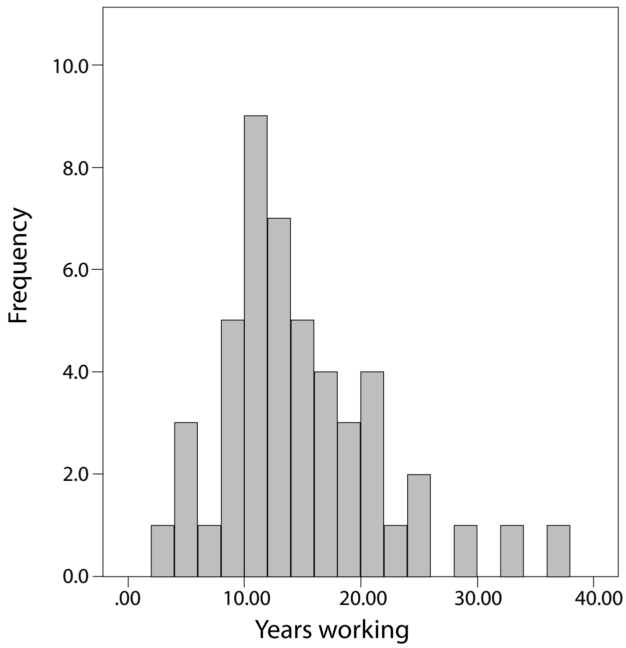


**Figure 3.** Years working distribution of ATC group

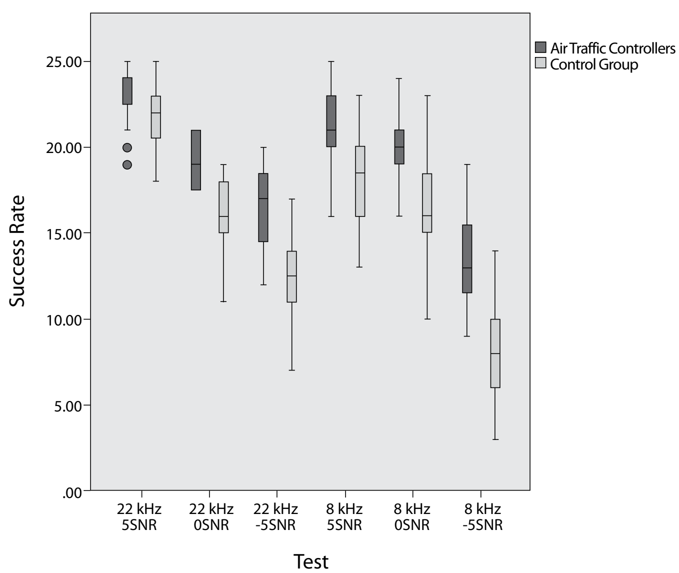


**Figure 4.** Success rate of ATC and control groups as a function of the test. The ATC group outperforms the control group in all SNR conditions and both in non-filtered (A=22 kHz) and filtered (B=8 kHz) conditions

## Procedures

The experiment took place in a quiet room with the listener sitting 1 m away from two loudspeakers. For technical details, please refer to the article by de Ramos de Miguel et al [23].

The data were recorded in an .xls file; Microsoft Excel 2011 (Microsoft; Redmond, Washington, USA) and IBM SPSS Statistics for Macintosh, V. 21.0. (IBM Corporation; NY, USA) were used for the statistical treatment. The statistical analysis began with a normality check for each specific condition using the Kolmogorov-Smirnov test for one sample. According to the result, a non-parametric or a two tailed t-student test was performed. Finally, correlations between age, years of experience in the aeronautic field, and test scores were analyzed using a Pearson correlation test. The level of significance chosen was 0.05.

**Table 1.** Pearson correlation of age, years working as an ATC, and overall test results. No correlation was found between test results and either age or experience. Obviously, in the vast majority of cases, the older the ATC, the longer the subject has worked in this field; thus, there is a correlation between these two variables

| | Age | Years working as an ATC | Test results |
|---|---|---|---|
| **Age** | | | |
| Pearson Correlation | | .759 | −.068 |
| Sigma (bilateral) | - | .000 | .249 |
| N | | 288 | 288 |
| **Years working as an ATC** | | | |
| Pearson Correlation | .759 | | .002 |
| Sigma (bilateral) | .000 | - | .973 |
| N | 288 | | 288 |
| **Test results** | | | |
| Pearson Correlation | −.068 | .002 | |
| Sigma (bilateral) | .249 | .973 | - |
| N | 288 | 288 | |

ATC: air traffic controller; N: number of samples

## RESULTS

First, the overall performance difference between the two groups was analyzed. Figure 4 shows that the ATC group outperforms the control group in both conditions, filtered and non-filtered, for all SNR conditions. Moreover, the difference between the groups becomes larger as the noise increases. A normality check gave Gaussian distributions. The evaluation of the significance returned p values <0.05 for all cases, thus revealing significant differences between the two groups. For SNR 5 dB, this difference was 7.27% for list A and 13.25% for list B; t(46)=2.01, p=6.31E-05, and t(49)=2.01, p=6.12E-08. For SNR 0 dB, these values rise to 16.95% and 11.45%; t(61)=2.00, p=2.40E-07, and t(49)=2.01, p=5.28E-07. The most interesting difference is observed at SNR −5 dB. In this case, the ATCs outperformed the control group by 17.03% and 22.52%; t(55)=2.00, p=2.88E-10, and t(55)=2.00, p=3.59E-13.

Figures 5 and 6 illustrate the relationships between years working as an ATC and test performance and between age and test performance. The correlation results between age, years working in this profession, and overall test results for each condition are shown in Table 1. No significant correlation was found between working experience and overall test results. A detailed analysis of each case revealed significant (p<0.05) inverse correlations between the 8 kHz 5 SNR test results and both variables. 22 kHz 5 SNR also gave a significant, inverse link between age and test results (Table 2).

Air traffic controllers performance was also evaluated independently to study the effect of high frequency filtering on speech perception in noise. The statistical differences between the A and B lists were reviewed to evaluate if filtering affects ATCs as much as the control group from the previous study, where high frequency filtering significantly affected speech recognition in noise, suggesting that NH subjects use high frequencies above 8 kHz to identify speech in noise.

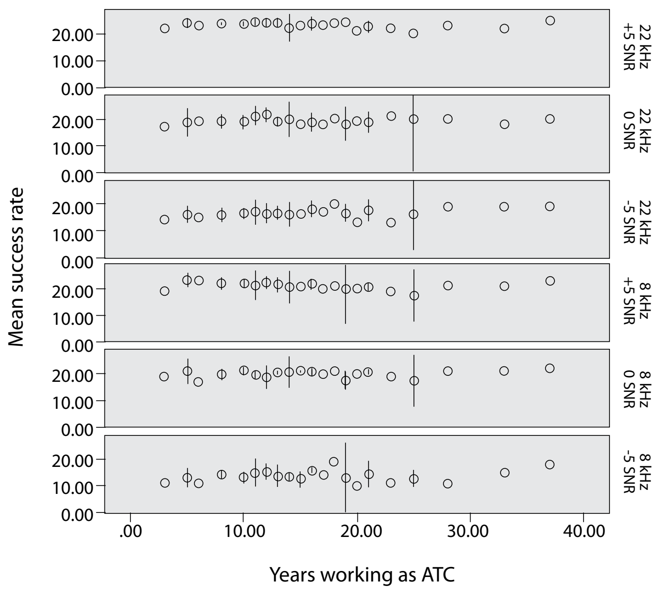


**Figure 5.** Success rate in each test as a function of years working as an ATC

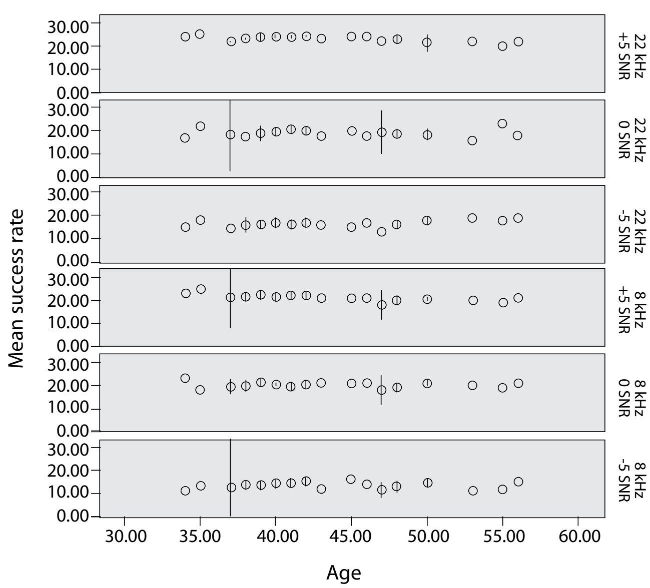


**Figure 6.** Success rate in each test as a function of age for the ATC group

The ATC group performed better when words were not filtered, with p<0.05 in all SNR conditions. For 5 dB SNR, 7.95% more words were correctly identified in list A; t(83)=1.99, p=5.20E-07. For 0 dB SNR, 5.08% more words were guessed correctly; t(94)=1.99, p=0.0050. Finally, for –5 SNR, a difference of 11.2% is observed between the A and B lists; t(94)=1.99 p=3.92E-08. The results indicate that ATCs are also affected by high frequency removal from speech. In this case, the effect was observed for all SNR conditions.

## DISCUSSION

Many studies have dealt with SIN training. Song et al. [22] studied training-related malleability using a program that incorporates cognitively based listening exercises to improve SIN perception. 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 time that short-term training was shown to have the potential to improve neural mechanisms for SIN perception. These results involve and define biological mechanisms that contribute to learning success, and they provide a conceptual increase in our understanding of the kind of training that can influence sensory processing in adulthood [22]. More recently, Sweethow and Sabes [24] prospectively assessed the generalization of SIN training in a cohort of individuals with hearing loss. Whitton et al. [25] prospectively assessed the effect of signal-in-noise, audio-game training on speech understanding in noise with untrained materials [25]. On the other hand, Fu and Galvin [26] and Moore and Shannon [27] have shown that targeted auditory training can further enhance the benefits of new implant devices and/or speech processing strategies. These findings and those from our study suggest that SIN training could be beneficial both for CI users and for those with moderate hearing loss be-

**Table 2.** Correlation between years working, age, and individual test results. Significant inversed correlations were found for a) 8 kHz 5 SNR and years working; b) 8 kHz 5 SNR and age; c) 22 kHz 5 SNR and age

| | Years working as an ATC | Age |
|---|---|---|
| **Years working as an ATC** | | |
| Pearson Correlation | 1 | .759 |
| Sig. (bilateral) | | .000 |
| N | 48 | 48 |
| **Age** | | |
| Pearson Correlation | .759 | 1 |
| Sig. (bilateral) | .000 | |
| N | 48 | 48 |
| **8 kHz 5SNR** | | |
| Pearson Correlation | -.288 | –.411 |
| Sig. (bilateral) | .047 | .004 |
| N | 48 | 48 |
| **8 kHz 0SNR** | | |
| Pearson | .012 | -.141 |
| Sig. (bilateral) | .937 | .340 |
| N | 48 | 48 |
| **8 kHz –5SNR** | | |
| Pearson Correlation | .134 | –.021 |
| Sig. (bilateral) | .363 | .886 |
| N | 48 | 48 |
| **22 kHz 5SNR** | | |
| Pearson Correlation | –.279 | –.503 |
| Sig. (bilateral) | .055 | .000 |
| N | 48 | 48 |
| **22 kHz 0SNR** | | |
| Pearson Correlation | .049 | –.040 |
| Sig. (bilateral) | .741 | .787 |
| N | 48 | 48 |
| **22 kHz –5SNR** | | |
| Pearson Correlation | .264 | .188 |
| Sig. (bilateral) | .069 | .200 |
| N | 48 | 48 |

ATC: air traffic controller; N: number of samples; SNR: signal-to-noise ratio cause it equips patients with the cognitive tools to confront complex auditory situations.

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. [28] investigated the effect of musical training on speech-in-noise (SIN) performance. They found that musical experience improves the ability to understand speech in challenging listening environments. The results also suggested that this enhancement is derived in part from musicians' remarkable working memory and frequency discrimination [28].

The results in this study indicate that ATCs, 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, the ATCs obtained better scores than the control group. The authors believe that this is due to the effect of training that occurs naturally during their daily activities. 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 because the first thing that subjects said 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; ATCs could identify more words than the standard NH population. It is likely, given the hypotheses proposed in the studies reviewed here that ATCs are better at focusing on less degraded acoustic speech cues and then filling the gaps using cognitive skills in the presence of background noise, requiring a lower time of adaptation and therefore missing less information.

However, correlations between years working and age did not return clear results. The two cases where significant correlations were found do not seem meaningful in the context of the other tests. If a correlation of any kind is to be established between these two variables, then consistency across tests is required. Thus, the results observed are likely to be caused by the limited number of subjects, which is an unfortunate but common aspect in clinical studies, due to the difficulty of recruiting volunteers. In such cases, statistics must be treated with care. It is possible and very likely, given the time taken by the subjects in the studies mentioned previously (approximately six months to one year) that the learning curve is steeper during their first year of training and approaches a plateau thereafter. Thus, another study emerges as a very interesting continuation of the present one, where ATCs in training are evaluated longitudinally during this time. Perhaps looking more closely into this period of the working lives of ATCs will reveal a significant correlation between SIN identification and training duration.

Interestingly, the two groups had statistically significant better results when the unfiltered lists were used. These results indicate that performance decreases when high frequency components of speech are removed. This can imply that frequencies above 8 kHz can help humans to better understand SIN. To draw further conclusions, a more specific experiment needs to be designed, where groups of words with similar high frequency contents are selected to try and establish a relationship between identification of a word and its frequency content because the speech material used has balanced phoneme content.

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 desirable to develop strategies to slow this process as much as possible. Given the recent proof 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 important implications in the treatment of hearing loss today. Hence, research in the line of this study will certainly aid in the development of efficient and effective training protocols and materials.

**Ethics Committee Approval:** Ethics committee approval was received for this study from the ethics committee of Complejo Hospitalario Universitario Insular Materno Infantil.

**Informed Consent:** Written informed consent was obtained from patients who participated in this study.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept - M.T.P.Z., A.R.D.M.; Design - M.T.P.Z., A.R.D.M.; Supervision - D.P.P., A.R.M.; Resources - M.T.P.Z., A.R.D.M., M.L.Z.G.; Materials - M.T.P.Z., A.R.D.M.; Data Collection and/or Processing - M.T.P.Z., A.R.D.M.; Analysis and/or Interpretation - M.T.P.Z., D.P.P.; Literature Search - M.T.P.Z.; Writing Manuscript - M.T.P.Z.; Critical Review - D.P.P., A.R.M.; Other - M.L.Z.G.

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**Conflict of Interest:** No conflict of interest was declared by the authors.

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