SUN-test (Speech Understanding in Noise): a method for hearing disability screening

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Abstract

The SUN-test (Speech Understanding in Noise) is a speech-in-noise test to screen adults and older adults for hearing disability. The SUN-test consists in a short list of intervocalic consonants (VCV, vowel-consonant-vowel) in noise that are presented in a three-alternatives forced choice (3AFC) paradigm by means of a touch-screen interface. Based on the number of stimuli correctly identified, the tested subject gets one of three possible test outcomes: *no listening difficulties, a hearing check would be advisable*, or *a hearing check is recommended*. This paper reviews the main results obtained with the SUN-test in the Italian language in a population of nearly 1,300 adults and older adults with varying degrees of audiometric thresholds and audiometric configurations, tested both in low and in high ambient noise settings. Results obtained in the tested population revealed that the outcomes of the SUN-test were in line with the outcomes of pure-tone testing, and that the test performance was similar both in low and in high ambient noise (up to 65 dB A). Results obtained with the SUN-test were not biased by the age of the subject because the performance of younger and older subjects in the test was similar. The mean duration of the SUN-test was nearly 40 s/ear, and was lower than 1 minute per ear even in subjects older than 80 years so that both ears could be tested, on average, in 2 minutes. The SUN-test was considered *easy* or *slightly difficult* by nearly 90% of subjects; test duration was judged *short* or *fair* by nearly 95% of subjects, and the overall evaluation of the test was *pleasant*, or *neutral*, in more than 90% of subjects. Overall, results of this study indicated that the SUN-test might be feasible for application in adult hearing screening. The test is fast, easy, self convincing, and reflects differences in hearing sensitivity between the tested subjects. The outcomes of the SUN-test were not influenced by the noise level in the test room (up to 65 dB A) indicating that the test, as such, might be feasible to screen adults and older adults both in clinical and in non clinical settings, such as convenient care clinics, hearing aid providers, or pharmacies, where the ambient noise is, typically, not controlled.

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Key words: hearing screening, hearing disability, adults, elderly, speech-in-noise, consonants.

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Introduction

Hearing disability is indeed one of the most common chronic health conditions in older adults, and has important implications for the quality of life, in that it may generate burdening effects such as functional decline, depression and social isolation (see, e.g. Arlinger, 2003; Carabellese *et al*., 1993; Weinstein & Ventry, 1982).

It is estimated that nearly 50 percent of persons over the age of 60 years, and more than 80 percent over 70 years, experience some degree of hearing loss (Cruickshanks *et al*., 1998; 2010).

Yet, hearing impairment in adults is still largely underdetected and undertreated, in the lack of accepted guidelines, protocols and legislation (Liu *et al*., 2011; Yueh *et al*., 2003; 2010). Remarkably, in most cases hearing loss in adults takes a long time to develop: it is a progressive process, and does produce a slow habituation to the impairment. It is documented that typically most hearing aid users have lived with hearing loss for more than ten years before seeking a hearing aid and that, as a result, their impairments have typically progressed from moderate to severe levels (Davis *et al*., 2007).

As early as in 1991, Mulrow & Lichtenstein (1991) had argued that the three commonly accepted criteria for a community screening program are, actually, satisfied for adult hearing screening, i.e.: i) the burden of disability is significant enough; ii) effective treatments are available, and iii) accurate, practical, and convenient screening tests exist. Remarkably, the need to establish effective programs of adult hearing screening and early intervention is being increasingly emphasized (Davis *et al*., 2007; Grandori *et al*., 2009). Some recent initiatives and projects have promoted awareness and research on adult hearing screening such as, for example, the 2009 NIDCD/NIH Working Group (Donahue *et al*., 2010), the Project AHEAD III (2008-2011) or Project HearCom (2004-2009). Significantly, medium and large scale pilot pro-

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grams of adult hearing screening have been established in Europe in the very last years, e.g. in the United Kingdom, the Netherlands, Italy, and Cyprus (Grandori *et al*., 2009; see also Paglialonga *et al*., 2011 and Thodi *et al*., 2011).

In line with the World Health Organizations International Classification of Functioning, Disability and Health (World Health Organization, 2001), consensus is emerging that hearing screening in adults should move from the screening of an *impairment* (which is a loss or abnormality in body structure or physiological function) to a screening of a hearing handicap or hearing *disability* (Danermark *et al*., 2010). Some individuals with hearing impairment may not perceive any hearing disability and, vice versa, others with minimal or no hearing impairment may report considerable disability (Schow, 1991). This is particularly true in adults and older adults, because hearing *(dis)ability* is a combination of peripheral and cognitive processing (Schneider *et al*., 2010; Pichora-Fuller & Singh, 2006) that requires, concurrently, the ability to hear, to listen, to comprehend, and to communicate (Kiessling *et al*., 2003), and so the deficits in communication that result from a decrease in hearing sensitivity may be commonly compounded by a decrease in the ability to understand speech in a background of competing noise or speech (Gates *et al*. 2008).

As a matter of fact, in the seventh to the ninth decades of life the decline in speech understanding is, typically, significantly faster than the decline in peripheral hearing sensitivity, particularly when speech is distorted, reverberated, or presented in noise (Divenyi *et al*., 2005; Akeroyd, 2008). Measures of hearing impairment are only a partial picture of disability and are not a reliable predictor of the lived experience of hearing handicap and disability. It is no surprise that the most common complaint of adults with self reported hearing disability is just the difficulty to understand speech in situations with background noise, reverberation, or competing speech (Kramer *et al*., 1998). Speech-in- noise tests, which are sensitive to declines both in hearing sensitivity and distortion, are widely acknowledged measures of the ability to hear in noise and can target the real experienced listening difficulties in adults more effectively than pure-tone audiometry (Killion & Niquette, 2000).

The SUN-test (*Speech Understanding in Noise*) is a speech in noise test that was recently developed and optimized to screen adults and older adults for hearing disability (Grandori *et al*., 2010). The SUN-test is composed of a short list of intervocalic consonants (VCV, vowel-consonant-vowel) in noise that have been normed for intelligibility, and that are presented in a three-alternatives forced-choice (3AFC) paradigm by means of a touch-screen interface. Based on the number of VCV correctly identified, the tested subject gets one of three possible test outcomes: *no listening difficulties, a hearing check would be advisable*, or *a hearing check is recommended*. The test was first developed in the Italian language and then adapted also in other languages, such as English, German, French, and Spanish.

Overall, the SUN-test in various languages has been administered to about 2,500 adults in an age range of 13 through 95 years. This paper reviews the main results obtained with the SUN-test in the Italian language in a population of ~1,300 adults and older adults with varying degrees of audiometric thresholds and audiometric configurations, tested both in low and in high ambient noise. The performance and the main features of the SUN-test will be illustrated, and the feasibility of using the SUN-test to screen adults and older adults, either in clinical or in non clinical settings, will be discussed.

Methods

In the results discussed here, a population of 1,273 subjects (aged 13-89 years) were tested with the SUN-test in the Italian language. Subjects were all mother-tongue Italian speakers. All subjects also underwent air conduction pure tone audiometry (PTA) at 1, 2, and 4 kHz. To evaluate the feasibility of using the SUN-test as a screening tool also in non clinical environments such as, for example, convenient care clinics, hearing aid providers, or pharmacies where, typically, the ambient noise is higher than in clinical settings, the same testing procedure was performed in two different settings:

i) *low ambient noise* settings (default settings). Testing was performed in quiet rooms, where the ambient noise was checked to be below the maximum permissible ambient sound pressure levels set by standard ISO 8253-1 (ISO, 1989). A group of 374 subjects (173 males, 201 females; age 14-89 yrs, mean age 63 yrs, s.d. 13 yrs) were tested in low ambient noise settings; of these, 41 subjects had unilateral hearing aids and were tested only in the unaided ear, whereas the remaining 333 subjects were tested in both ears, for a total of 707 ears tested;

ii) *high ambient noise* settings. Testing was performed in booths placed close to underground stations, main railway stations and drugstores. The ambient noise was measured every day, in each booth and in each location and was, on average, 65 dB A (s.d. 3 dB). A group of 899 subjects (387 males, 512 females; age 13-87 yrs, mean age 53 yrs, s.d. 16 yrs) were tested in high ambient noise settings; of these, 60 subjects had unilateral hearing aids and were tested only in the unaided ear, whereas the remaining 839 subjects were tested in both ears, for a total of 1,738 ears tested.

At the end of the test session, all subjects were asked to fill in an evaluation questionnaire to give their feedback on the whole test procedure. The questions were: i) How would you grade the task? (easy/slightly difficult/difficult); ii) How would you grade test duration? (short/fair/long); and iii) Overall, how would you grade the test? (pleasant/neutral/stressful).

Table 1. Distribution of the SUN-test outcomes obtained in low ambient noise (upper table) and in high ambient noise (lower table). In subjects tested bilaterally, test outcome was given based on the worse ear. Numbers and percentages are reported both over the total number of ears tested (center column) and over the total number of subjects tested (right-hand columns).

Low ambient noise	N. of Ears	N. of Subjects	
		Tested unilaterally	Tested bilaterally
No listening difficulties	379/707 (53.6%)	14/374 (3.7%)	122/374 (32.7%)
A hearing check would be advisable	226/707 (32.0%)	6/374 (1.6%)	143/374 (38.2%)
A hearing check is recommended	102/707 (14.4%)	21/374 (5.6%)	68/374 (18.2%)

High ambient noise	N. of Ears	N. of Subjects	
		Tested unilaterally	Tested bilaterally
No listening difficulties	806/1738 (46.4%)	14/899 (1.5%)	241/899 (26.8%)
A hearing check would be advisable	601/1738 (34.6%)	23/899 (2.6%)	350/899 (38.9%)
A hearing check is recommended	331/1738 (19.0%)	23/899 (2.6%)	248/899 (27.6%)

Results

Table 1 shows the distribution of the SUN-test outcomes obtained in the 374 subjects (707 ears) tested in low ambient noise and in the 899 subjects (1,738 ears) tested in high ambient noise.

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In low ambient noise settings, more than half (53.6%) of the ears tested with the SUN were found to have no listening difficulties, about one third (32.0%) were advised to do a hearing check, and nearly 15% were recommended to do a hearing check. Similarly, in high ambient noise slightly less than half of the tested ears (46.4%) were found to have *no listening difficulties*, about one third (34.6%) had *a hearing check would be advisable* as test outcome, and nearly 19.0% had a *hearing check is recommende*d as test outcome. In Table 1 the distribution of the SUN-test outcomes is also shown with respect to the number of subjects tested, whereby in subjects tested bilaterally the test outcome was given based on the worse ear. Again, it could be observed that comparable results were obtained in the two different test settings: 30-35% of subjects were classified in the *no listening difficulties* category, nearly 40% were advised to do a hearing check, and less than 30% were recommended to do a hearing check.

Depending on the PTA thresholds at 1, 2, and 4 kHz, the tested ears were also classified into one out of three PTA classes: Class I included ears with thresholds ≤40 dB HL at 1, 2, and 4 kHz; Class II included ears with thresholds ≤40 dB HL at 1 and 2 kHz and threshold > 40 dB HL at 4 kHz; and Class III included ears with thresholds > 40 dB HL at 2 and 4 kHz.* As a result, of the 707 ears tested in low ambient noise, 468 ears were assigned to Class I, 146 to Class II, and 93 to Class III; of the 1,738 ears tested in high ambient noise, 1,469 ears were assigned to Class I, 199 to Class II, and 70 to Class III.

The distribution of the SUN-test outcomes in ears classified in each of the three PTA classes is shown in Table 2 for both test settings: low ambient noise and high ambient noise.

From Table 2 it could be observed that there was a straightforward correlation between the three PTA classes and the three SUN-test categories: the majority (65%) of ears in PTA Class I (i.e., ears with thresholds ≤40 dB HL up to 4 kHz) tested in low ambient noise had no listening difficulties in the SUN-test, and only a minor percentage (6%) of ears in PTA Class I were recommended to do a hearing check. Vice versa, the majority (~84%) of ears in PTA Class III (i.e., ears with thresholds >40 dB HL at least at 2 and 4 kHz) were either advised (34.4%) or recommended (49.5%) to do a hearing check, and only 16% of them had no listening difficulties in the SUN-test. The straightforward correlation between the three SUN-test categories and the three PTA classes was also observed in high ambient noise settings. Nearly half (50.4%) of ears in PTA Class I had *no listening difficulties* in the SUN-test, and only a minor percentage (16%) of them were recommended to do a hearing check. Vice versa, the majority (~84%) of ears in PTA Class III were either advised (28.6%) or recommended (55.7%) to do a hearing check, and nearly 16% of them had *no listening difficulties* in the SUN-test. As to ears in PTA Class II, nearly 41% fell in the *a hearing check would be advisable* category both in low and in high ambient noise settings, whereas the proportion of ears classified in the *no listening difficulties* category varied in the range 28-39%, and – dually – the proportion of ears in the a *hearing check is recommended* category varied in the range 19-31%. Because the PTA Class II includes ears with thresholds higher than 40 dB HL at 4 kHz but *not* at 2 kHz, it is reasonable to expect a higher variability of speech-in-noise recognition performance, as documented in the literature. As a matter of fact, the pure tone threshold at 4 kHz is not *per se* an adequate predictor of speech reception threshold, but only if combined with thresholds at lower frequencies, at least at 2 kHz (Smoorenburg, 1992). Accordingly, Ventry & Weinstein (1983) recommended not to rely on a fail at 4 kHz when screening for hearing handicap with pure tone thresholds.

Hearing thresholds at 4 kHz can be thus expected to be poorly correlated with speech in noise performance, whereas the combination of hearing thresholds at 4 *and* 2 kHz is a better predictor of the ability to hear speech in noise. Results previously observed in ears in PTA Class I and Class III (i.e., ears with thresholds either lower or higher than 40 dB at both 4 and 2 kHz), are in line with these evidences because the agreement between the SUN-test outcomes and PTA was more straightforward.

The outcomes of the SUN-test were also studied as a function of the age of the tested subjects. Figure 1 shows the mean test score (i.e., the number of VCV correctly identified by the tested subjects) as a function of age, in ears classified in each of the three PTA classes. The maximum score that can be obtained with the SUN-test in the Italian language is 12. Data in Figure 1 are from ears tested in low ambient noise settings; results obtained in high ambient noise settings were fully comparable. Statistical analysis (Kruskal Wallis test) revealed that there was no significant effect of age on mean test score in ears belonging to PTA Class II and Class III, neither in low ambient noise settings (Class II: χ^2=11.21, df=7, P=0.1297; Class III: χ^2=9.45, df=7, P=0.2217) nor in high ambient noise settings (Class II: χ^2=15.31, df=7, P=0.065; Class III: χ^2=11.01, df=7, P=0.137). The only significant effect

Table 2. Distribution of the SUN-test outcomes in ears classified in each of the three PTA classes, in low ambient noise (upper table) and in high ambient noise (lower table). Numbers and percentages are reported over the total number of ears classified in each of the three PTA classes.

Low ambient noise	Pta Class		
	Class I	Class II	Class III
No listening difficulties	306/468 (65.4%)	57/146 (39.0%)	15/93 (16.1%)
A hearing check would be advisable	133/468 (28.4%)	61/146 (41.8%)	32/93 (34.4%)
A hearing check is recommended	29/468 (6.2%)	28/146 (19.2%)	46/93 (49.5%)
High ambient noise	**Pta Class**		
	Class I	Class II	Class III
No listening difficulties	740/1469 (50.4%)	55/199 (27.6%)	11/70 (15.7%)
A hearing check would be advisable	499/1469 (34.0%)	82/199 (41.2%)	20/70 (28.6%)
A hearing check is recommended	230/1469 (15.6%)	62/199 (31.2%)	39/70 (55.7%)

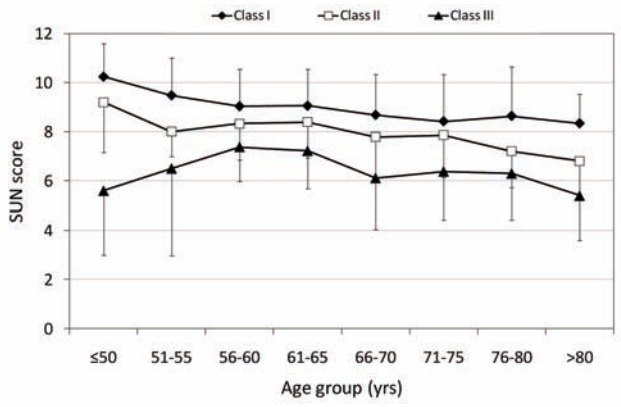

Figure 1. Mean values (± 1 s.d.) of the SUN-test scores as a function of age in the 707 ears tested in low ambient noise, in each of the three PTA classes.

**The cut-off value of 40 dB HL was set following the suggestions by Ventry & Weinstein (1983) for adult hearing screening, also in line with the definition of disabling hearing impairment given by the World Health Organization (2008) and the threshold used by the Veterans Health Administration to define hearing loss (US Congress, 1987).*

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of age was found in the youngest age group in PTA Class I both in low (χ^2=48.13, df=7, P≈10^{-8}) and in high ambient noise settings (χ^2=202.58, df=7, P≈0), because ears in the youngest age group (i.e., ≤50 years) had a significantly higher mean score than all the other age groups (Mann Whitney post-hoc test; P<0.05), whereas no statistically significant differences in test scores were observed among all the other age groups in ears in PTA Class I. Thus, with the exception of the youngest age groups in PTA Class I, the outcomes of the SUN-test in each of the three PTA classes did not vary with increasing age. The only significant effect was a better test outcome only in the youngest subjects with good hearing thresholds (PTA Class I). Stated differently, the performance of younger and older adults in the SUN-test was indeed the same, provided that differences in hearing sensitivity were taken into account.

The time needed to complete the SUN-test was also measured. Overall, the mean test time was 41 s/ear (s.d. 10 s); the lowest test time was 26 s/ear (in a very young subject aged 22 years tested in high ambient noise), and the highest was 114 s/ear (in a subject aged 72 years tested in low ambient noise). Figure 2 shows the mean test time as a function of age in ears tested in low ambient noise settings; results obtained in high ambient noise settings were identical. As illustrated in Figure 2, test time increased with increasing age, from an average of about 36 s/ear in subjects younger than 50 years to 48 s/ear in the older age groups. The observed increase of test time with age was statistically significant (one-way ANOVA test, F=9.38, df=7, P≈10^{-11}), indicating that – as can be expected – older subjects were slightly slower than younger ones in performing the SUN-test. However, the mean test time was in any case lower than 1 minute per ear, both in low and high ambient noise, even in the older age groups.

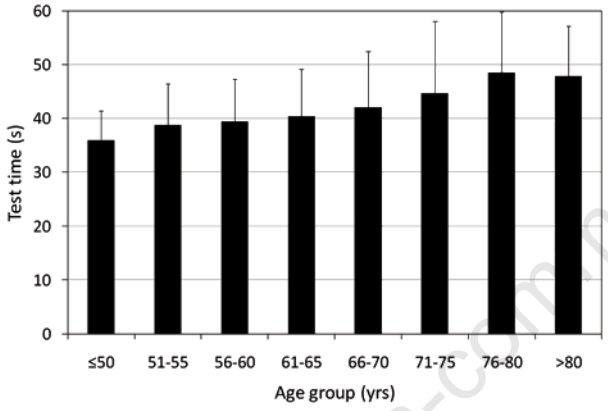

Figure 2. Mean values (± 1 s.d.) of test time as a function of age in the 707 ears tested in low ambient noise.

Table 3. Distribution of the answers to the evaluation questionnaire administered to the 374 subjects tested in low ambient noise (center column) and to the 899 subjects tested in high ambient noise (right hand column).

	Low ambient noise	High ambient noise
How would you grade the task?		
Easy	64%	60%
Slightly difficult	22%	24%
Difficult	14%	16%
How would you grade test duration?		
Short	70%	69%
Fair	26%	26%
Long	4%	5%
Overall, how would you grade the test?		
Pleasant	59%	55%
Neutral	34%	37%
Stressful	7%	8%

Table 3 reports results of the evaluation questionnaire administered to the 374 subjects tested in low ambient noise and to the 899 subjects tested in high ambient noise. The distributions of the answers given to the questionnaire in the two different test settings were almost identical. Overall, nearly 85% of the subjects reported the test easy (64%) or slightly difficult (22%) to be performed, whereas only 14% judged the test difficult. The vast majority of subjects (i.e., nearly 95%) rated the test duration as short (~70%) or fair (26%), whereas only a minor proportion of subjects (4-5%) considered the test long. As to the overall judgment of the SUN-test procedure, more than 55% of the tested subjects judged the test as pleasant, nearly 35% expressed no particular concern, and less than 8% rated the test as stressful.

Discussion

In this paper, the main results obtained using the SUN-test in the Italian language in a population of 1,273 adults, tested both in low and in high ambient noise settings were reviewed. In view of these results, the following main features of the SUN-test can be highlighted:

Fast test procedure

The mean duration of the SUN-test was ~40 s/ear, and ranged from nearly 35 s/ear for subjects aged ≤50 years to nearly 50 s/ear for subjects aged >80 years. Thus, test time was typically lower than 1 minute per ear and, in any case, lower than 1 ½ minutes per ear, even in the older age groups. The total time needed to test both ears was thus, on average, 2 minutes, and never exceeded 3 minutes even in the older subjects. This is particularly relevant to adult hearing screening, because when the test duration increases, inattentiveness and fatigue are likely to occur and may alter the test outcomes, particularly in older subjects.

Reliability

The outcomes of the SUN-test were in line with the outcomes of pure tone testing in adults tested both in low and in high ambient noise (see Table 2). For example, 65% of ears with good pure tone thresholds (PTA Class I) tested in low ambient noise were classified in the category *no listening difficulties* by the SUN-test, whereas 70% of ears with poor pure tone thresholds (PTA Class III) were classified in the *a hearing check would be advisable* or a *hearing check is recommended* categories. Remarkably, the observed agreement between the SUN-test outcomes and PTA is fully in line with what reported in the literature for existing, and more time-consuming, speech in noise tests, for which the correlation with pure tone thresholds (normally averaged in the range 0.5-4 kHz) is typically lower than 0.7 (Bosman & Smoorenburg, 1995; Wilson *et al*., 2007).

Low cognitive load

The analysis of test scores and test duration as a function of age (Figures 1 and 2) showed that, once ears are classified based on their PTA Class, the mean score in the SUN-test did not vary with increasing age, neither in low ambient noise nor in high ambient noise; also, test time remained lower than 1 minute per ear even in the older subjects. Stated differently, the performance of younger and older subjects in the SUN-test was strikingly similar, thus indicating that the cognitive load associated with the task was limited and did not influence the test outcomes in the older subjects. A limited cognitive load is particularly relevant to adult screening because it is well known that, especially in

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older adults, an increase in the cognitive load associated with a listening task typically can lead to a dramatic decrease in the subject's listening performance.

Acceptability

Results of the evaluation questionnaire in both low and high noise settings showed a favourable feedback from the tested population. The SUN-test was considered *easy* or *slightly difficult* by nearly 90% of subjects; test duration was judged *short* or *fair* by nearly 95% of subjects, and the overall evaluation of the test was *pleasant* or *neutral* in more than 90% of subjects. By the use of simplified interactions and a short test sequence, the perceived complexity of the task was kept to a minimum. Also, the preliminary instructions on how to use the touchscreen and how to perform the test were easy to understand and typically required less than 1 minute, in such a way that the SUN-test can be considered nearly a self administered test. Acceptability of the test procedure represents a significant added value in hearing screening because it could be helpful to increase the subjects awareness of their decreased hearing ability and, thus, possibly improve their attitude to behaviour change.

Feasibility

Results observed in high ambient noise settings were strikingly similar to results obtained in low ambient noise, indicating that the outcomes of the SUN-test were not influenced by the noise level in the test room (at least up to 65 dB A) and that the test, as such, might be feasible to screen adults both in clinical and in non clinical settings, such as convenient care clinics, hearing aid providers, or pharmacies, where the ambient noise is, typically, not controlled.

Conclusions

Overall, results of this study indicated that the SUN-test might be feasible for application in adult hearing screening. The test is fast, self convincing, acceptable and, also, reflects differences in hearing sensitivity between the tested ears. Results obtained with the SUN-test are not biased by the age of the subject: the performance of younger and older subjects in the test is similar and the test time is low even in the oldest subjects. This is because the cognitive load associated with the SUN-test is low and does not influence the test outcomes, even in the older age groups. The outcomes of the SUN-test are, also, not influenced by the noise level in the test room (up to 65 dB A), indicating that the test, as such, is feasible to screen adults both in clinical and in non clinical settings, such as convenient care clinics, hearing aid providers, pharmacies.

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