Towards Determining Distortion Product Otoacoustic Emission Protocols for Newborn Hearing Screening

Vers l'établissement de protocoles pour les oto-émissions acoustiques par produits de distorsion pour le dépistage auditif chez les nouveau-nés

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Abstract

Universal newborn hearing screening programs use a variety of technologies to accomplish their goals. Ensuring accurate results is important to minimize stress to families and decrease unnecessary referrals. This study reviews a cohort of 149 newborns who passed automated auditory brainstem response and also had distortion product otoacoustic emissions measured. The results show that the distortion product otoacoustic emission pass rates are lower at low frequencies and that test results could be improved by eliminating frequencies below 2.0 kHz. This study shows the need for screening programs to assess their pass protocols in terms of the number of frequencies and signal-to-noise ratio pass criteria. An important goal of universal newborn hearing screening is to attain acceptable sensitivity and specificity results. These results offer information regarding how to minimize false positives, thereby increasing the specificity of test results.

Abrégé

Les programmes de dépistage universel de la surdité chez les nouveau-nés utilisent différentes techniques. Il est important d'obtenir des résultats exacts pour minimiser les soucis occasionnés aux familles et faire diminuer le nombre d'enfants référés à des spécialistes. La présente étude passe en revue un groupe de 149 nouveau-nés qui ont subi le test automatisé des potentiels évoqués auditifs et chez qui on a aussi mesuré les oto-émissions acoustiques par produits de distorsions. Les résultats indiquent que les taux de « réussite » des oto-émissions acoustiques sont plus faibles à des fréquences basses et que les résultats des tests pourraient être meilleurs si l'on éliminait les fréquences de moins de 2 kHz. Cette étude signale le besoin des programmes de dépistage d'évaluer les protocoles de réussite en terme du nombre de fréquences et de critères de réussite par rapport aus ratio signal-bruit. Un objectif important du dépistage universel des nouveau-nés consiste à atteindre des résultats acceptables sur le plan de la sensibilité et de la spécificité. Ces résultats renseignent sur la façon de minimiser les faux négatifs, ce qui accroît la spécificité des résultats de tests.

Key words: newborn hearing screening, neonate, distortion product otoacoustic emissions

Early identification of hearing loss followed by appropriate and timely intervention is important for successful development of speech and language (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Furthermore, educational and social development are also improved by early identification and intervention in hearing impaired newborns (National Institute of Health, 1993). Because of this positive impact on outcomes, universal newborn hearing screening (UNHS) has become standard practice in many parts of the world. Although UNHS is becoming more widely applied, there are no standard screening approaches nor are the pass/fail criteria uniform from program to program. Most UNHS programs use combinations of automated auditory brainstem response (AABR), transient otoacoustic emissions or distortion product otoacoustic emissions (DPOAEs) to screen newborns for hearing loss (Dort, Tobolski, & Brown, 2000). A recent national survey revealed that most Canadian centers with screening programs utilizing otoacoustic emissions use DPOAEs as the initial screening test (Brown, Dort, & Sauve, this issue). A DPOAE occurs when two tones of different frequencies, f_1 and f_2, are used to stimulate the cochlea. The subsequent cochlear distortion response at $f_d = 2f_1 - f_2$ is then measured (Kemp, 1979; Probst, Lonsbury-Martin, & Martin, 1991).

As noted above, DPOAE protocols and pass/fail criteria differ between screening programs and also differ among the various screening tools available. In general, a DPOAE is present when the DPOAE amplitude is greater than the noise floor at a defined number of frequencies and by a predetermined signal-to-noise ratio (S/N) (Christensen, 2000). The goal of a screening program is to identify individuals with a problem (i.e., hearing loss) while avoiding false positives and false negatives (Christensen & Killion, 2000). Therefore DPOAE protocols and pass/fail criteria need to be designed with this goal in mind. Arbitrary application of DPOAE pass/fail criteria without consideration of specific technologies or normative data can make the goal of screening more difficult to achieve (Christensen & Killion; Gorga, Neely, & Dorn, 1999).

A lack of standards equates to differences in equipment and measuring techniques from manufacturer to manufacturer, which can hamper the development of universal pass/fail criteria. Individual equipment can measure responses that vary in both amplitude of the emission and its corresponding noise floor (Hornsby, Kelly, & Hall, 1996). Therefore, manufacturers often develop protocols based on their specific equipment. On the other hand, some companies prefer to allow investigators to develop their own protocols and pass/fail algorithms. The result is that DPOAE protocols vary widely, from S/Ns of anywhere between 3 (Lonsbury-Martin & Martin, 1990; Smurzynski, 1994) and 11 dB (Popelka, Karzon, & Arjmand, 1995), and this variance may affect the sensitivity and specificity of screening studies (Christensen & Killion, 2000; Gorga et al., 1999).

This study examined DPOAE data collected from a cohort of neonates who were tested with both AABR and DPOAE as part of a prospective population-based study. ABR is considered the definitive test for determination of normal hearing in newborns (Durieux-Smith, Picton, Bernard, MacMurray, & Goodman, 1991; Swigonski, Shallop, Bull, & Lemons, 1987). The present study analyzed a subset of babies who had normal AABR results. Therefore, this paper examined the issue of DPOAE false positive test results, where due to various test measures, infants with "normal" hearing are incorrectly identified as hearing impaired. The purpose of this research was to better define appropriate DPOAE test protocols as part of a UNHS program.

Methods

Participants

One hundred and forty-nine babies in the well-baby nursery (WBN) of the Foothills Hospital, Calgary, AB who had normal AABRs participated in this study. Participants were recruited according to their availability, by a process of informed parental consent. This research protocol was reviewed and approved by the Conjoint Medical Research Ethics Board of the University of Calgary.

Screening tests were performed by a trained registered nurse or by an audiology student. The infants were tested when sleeping or resting quietly. The babies were tested with AABR and DPOAEs in a quiet room within the WBN. These tests were done in a random order and both ears were tested beginning with the ear that presented first (i.e., whichever ear was facing up).

Testing Protocol

All testing was done with commercially available equipment and utilized a computer, an external unit and a sound delivery system (either insert earphones or probe) to deliver the auditory stimulus. The AABR (Smart Screener™ by Intelligent Hearing Systems) used a monaural (100 ms) click stimulus recorded with a forehead to ipsilateral mastoid electrode montage. The stimuli were presented at a repetition rate of 19.3 clicks/second at 70 and 35 dB nHL and the resultant waveform was filtered from 30 to 3000 Hz. The Smart Screener™ uses a pass criterion based on a cross correlation between two recordings at a given sound intensity. The cross correlation duration algorithm reduces chance correlations and measures the repeatability of two recordings over the time window (Intelligent Hearing Systems, 1994). In addition, the results from all participants were verified by a certified audiologist who considered wave V of the resulting ABR to be present if it replicated at both intensities and was present within normal values.

DPOAEs were measured with an Otoscape 942 system (Soundscape Technologies Inc.) which consisted of a portable computer, external digital signal processing unit and an

Table 1. Means and Standard Deviations of DPOAE Emission and Noise Floor Amplitudes (dB SPL) as a Function Of f_2 Frequency (kHz).

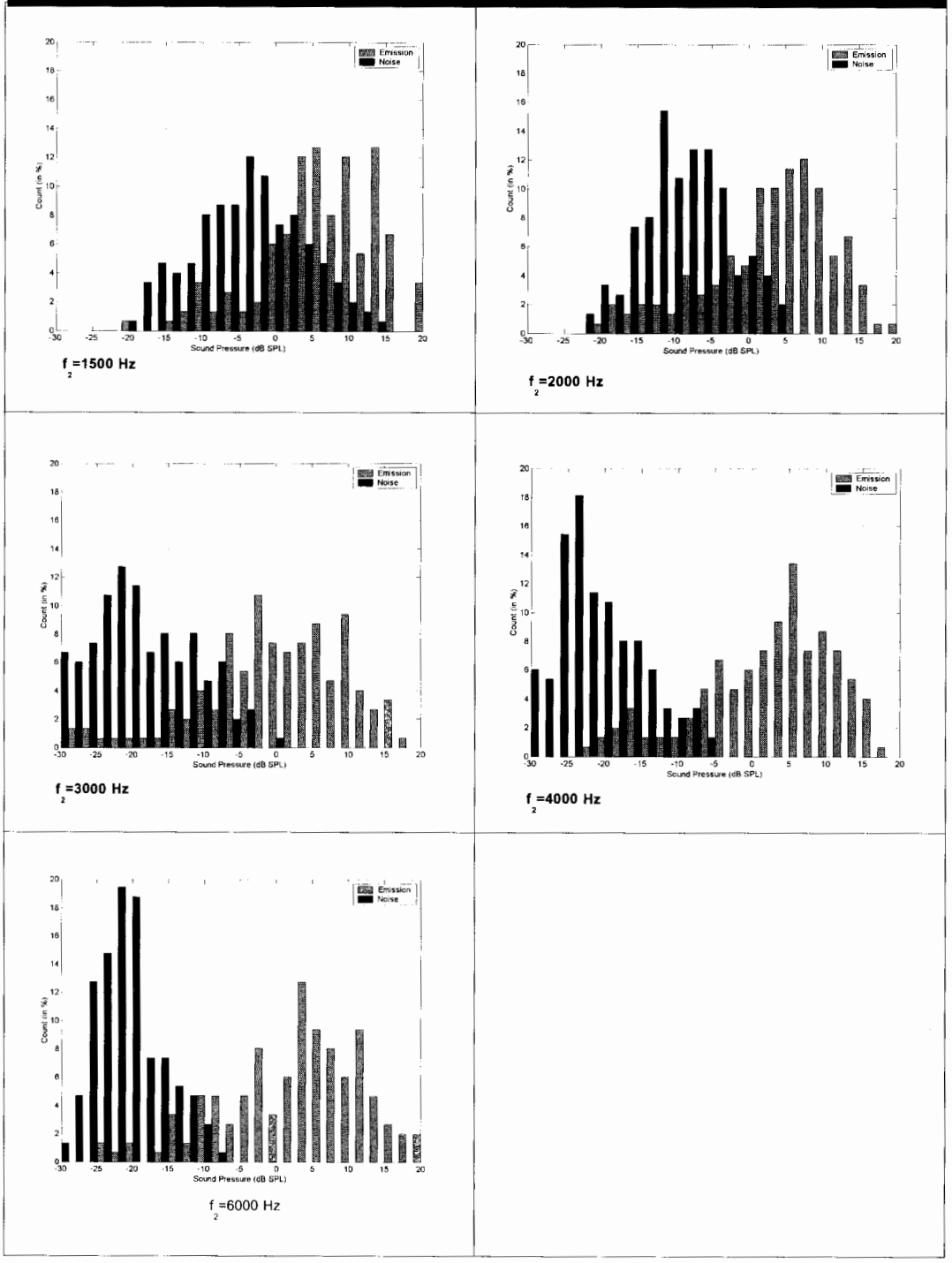
	Emission		Noise Floor	
f_2 Frequency	*Mean*	*SD*	*Mean*	*SD*
1.5	6.2	8.4	-3.7	7.8
2.0	3.7	8.4	-8.7	5.8
3.0	-0.9	11.3	-18.8	7.1
4.0	2.6	9.1	-21.0	6.0
6.0	2.6	9.6	-21.0	4.7

ER-10C ear probe to deliver the stimuli and record the acoustic signal in the ear canal. The DPOAE stimuli consisted of two tones (f_1 and f_2) with L1 = 60 and L2 = 45 dB SPL, and a f_2/f_1 ratio of 1.2 (Kimberley, Brown, & Allen, 1997) for the f_2 frequencies of 1.5, 2, 3, 4 and 6 kHz. The noise floor is calculated using a six Fast Fourier Transform bin approach. This calculation is made by averaging the power of the signal for three frequencies above and below the distortion frequency ($f_d = 2f_1 - f_2$).

Results

Figure 1 presents histograms of DPOAE noise floor and emission distributions (in dB SPL) as a function of f_2 frequency. The mean DPOAE emission and noise floor amplitudes as a function of f_2 frequency are presented in Table 1. As evident in Table 1, the mean noise floor amplitude decreases in the range from 1.5 to 3-6 kHz. In contrast, the DPOAE amplitudes remain stable at all frequencies tested. The noise floor is highest at low frequencies and the emissions are approximately equal across all frequencies. Therefore, separation between DPOAE noise floors and emissions, or S/N, is smallest for the low frequencies. This reduced S/N in the low frequencies is illustrated in Figure 1 by the increasing overlap between the noise and the emission in these frequencies.

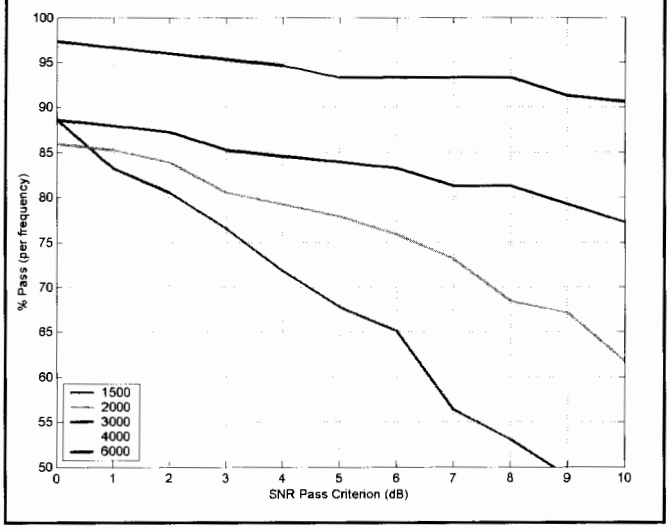
Figure 1. DPOAE emission and noise floor amplitude (in dB SPL) distribution histograms for f_2 frequencies 1.5 to 6 kHz.



DPOAE pass rates vary as a function of S/N pass criteria as shown in Figure 2. As expected, at all frequencies the pass rates decrease with increasing S/N pass criteria. However, this decrease is most noticeable in the lower f_2 frequencies. For example, for a S/N pass criterion of 6 dB, the pass rate at 1.5 kHz is approximately 65%. However, as the f_2 frequency increases the pass rate also increases to between 76% and 93% for the 2.0 and 6.0 kHz range.

DPOAE pass rates are shown in Figure 3 for increas-

Figure 2. Frequency specific DPOAE pass rates as a function of S/N.



ing S/N pass criteria. In Figure 3a each line indicates pass rates depending on whether a participant has an emission as defined by the pass criteria of at least three, four or five out of five f_2 test frequencies. As expected, it is more difficult to pass five out of five, versus three out of five f_2 frequencies. Figure 3b shows similar results when only four frequencies are considered (f_2 = 1.5 kHz is excluded). DPOAE pass rates improve when the 1.5 kHz f_2 frequency results are excluded.

Discussion

With the increasing use of distortion product otoacoustic emissions as a screening tool in newborn hearing screening programs, it has become critically important that the clinician fully understand this tool. The results consist of the amplitude of the distortion product and it's associated noise floor.

Individual differences in probes and algorithms influence the measurements. Differences across commercial products are due to probe microphone differences (Christensen, 2000; Christensen & Killion, 2000), leakage from the probe tube to the microphone (Siegel, 1995), and standing waves in the ear canal in the high frequencies which can cause calibration tone inaccuracies and consequent inaccuracies of DPOAE response levels (Siegel, 1994; Siegel & Hirohata, 1994). The amplitude of the emission can also be influenced by such things as measurement parameters (Gaskill & Brown, 1990) or age of the individual (Brown, Sheppard, & Russell, 1994; Kimberley et al., 1997; Lafreniere et al., 1991).

The result of this investigation found that newborns in the WBN had DPOAE emissions which were relatively similar across frequency. However, the pass rates were shown to vary by frequency (Figure 2). This reinforces the contention that there is a noise level problem at low frequencies. Low frequencies have high noise floors while exhibiting only average emissions. Therefore, the lowest frequencies resulted in the lowest pass rates.

To understand this result, the clinician should understand what influences the noise floor and how the noise floor is calculated. Noise floor measurements are influenced by factors such as environmental, participant and equipment noise (see Popelka, Karzon, & Clary, 1998 for review). It is also

Figure 3. DPOAE protocol pass rates as a function of S/N. Panel (a) shows pass rate with 1.5 kHz included in the test results while Panel (b) has 1.5 kHz excluded from the test results.

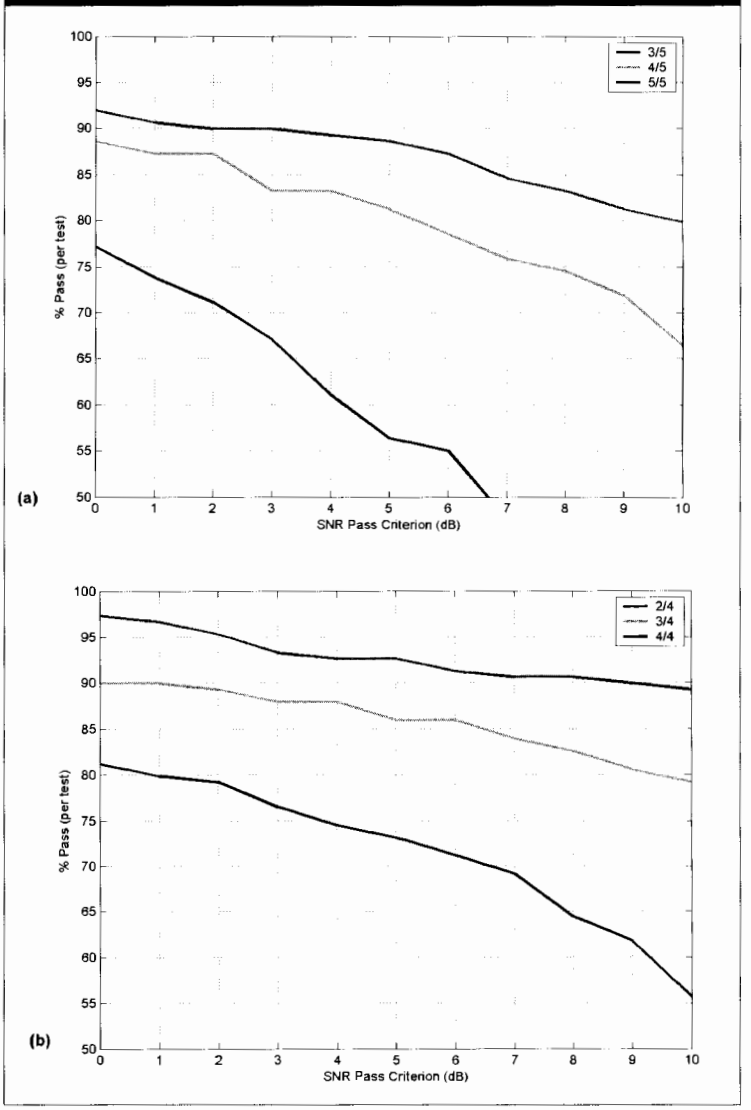
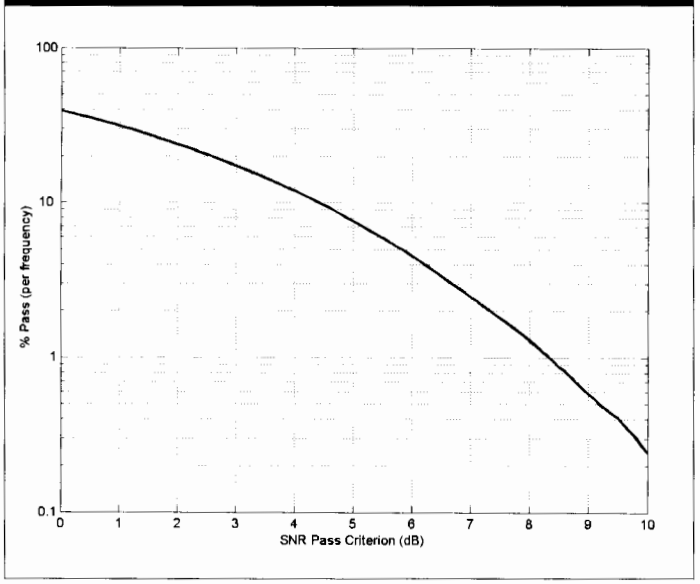


Figure 4. Theoretical probability of observing an emission when no true emission is present.



influenced by the method used to estimate the noise floor that is not standard across equipment (Kimberley et al., 1997). Therefore there are no standard noise floor estimation criteria.

The noise floor is generally higher at frequencies below approximately 2.0 kHz, since body, microphone and room noise are predominantly low frequency sounds. As the emission levels remain relatively constant at lower frequencies, it is difficult to detect emissions at those frequencies. This problem is compounded because the noise floor of a DPOAE is calculated at frequencies near the distortion frequency ($f_d = 2f_1 - f_2$), which is well below the test frequency of f_2. For example, the f_2=1.5 kHz test frequency measures the noise floor in the vicinity of 1.0 kHz.

Given the preceding information it would appear to be desirable to reduce the noise floor at a given frequency. In general, increasing the averaging time can reduce the noise floor of the DPOAE. For example, the noise floor could be reduced by three dB by doubling the test averaging time. However, longer averaging times are not often practical for a newborn population.

Given this understanding of the noise floor, these data suggest that 1.5 kHz is a difficult frequency to obtain in a WBN environment. Meaningful DPOAE measurements below 2.0 kHz can be obtained in a sound-treated room but this is not practical in a WBN. The percentage of passes at this low frequency is diminished when compared with the other test frequencies and may result in infants failing a hearing screening when they have normal hearing.

In an effort to improve pass rates it is tempting to manipulate the low frequency S/N pass criteria (see Figure 3). However, if the S/N pass criterion is set too low, a participant with no emissions could pass the screening test. This recording of spurious data can be illustrated by understanding that "false emissions" can occur in a cavity. The probability of detecting a false emission in a cavity as a function of the S/N pass criterion is shown in Figure 4 (see Kimberley et al., 1997 for review). As an example, the graph shows that for a S/N pass criterion of 3 dB at a single frequency, a cavity will appear to have an emission 17% of the time.

These theoretical calculations and the data from this study support using high S/N pass criteria and not including low frequencies such as 1.5 kHz. However, even a stringent 9 dB S/N pass criteria does not result in a sensitivity of 100% (Gorga et al., 1999). Other studies have shown similar results (Gorga et al., 2000; Musiek & Baran, 1997).

The number of frequencies to include in a DPOAE screening protocol will be influenced by the need to have a test that does not have too many false positive results. One is faced with a trade-off between the S/N pass criteria (high enough for adequate sensitivity), and the number of frequencies to include in a given test protocol. Some commercial screening devices use a test protocol with only three mid to high frequencies (i.e., f_2 = 2.0, 3.0, 4.0 kHz) omitting the frequencies below 2.0 kHz. Such an approach is supported by the data reported in the current study (see Figures 2 and 3).

A universal DPOAE protocol is not feasible and UNHS programs must rely on equipment manufacturers to provide normative data (Christensen, 2000; Hornsby et al., 1996). Therefore, clinicians should be familiar with the pass criteria used in their specific equipment. They should understand how it measures an emission, calculates the resulting noise floor, and what the rationale is behind the pass protocol and not just treat it as a "black box".

The real world interpretation of these results is to encourage readers to understand the importance of device specific differences with regards to interpretation of DPOAE results. The interpretation of DPOAE results is not as simple as it seems. Those using these devices need to inform themselves about the specifics of the device in order to make appropriate interpretations to families. Otherwise, using and interpreting results from a DPOAE device is like opening Pandora's box.

Author Notes

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