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LISTENING FOR MACHINERY MALFUNCTIONS IN NOISE WHILE WEARING EAR MUFFS

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ABSTRACT

It is generally believed by personnel who work in ships' engine and boiler rooms that the noise attenuation provided by an effective ear muff will adversely affect their ability to detect those sounds that indicate real or potential machinery malfunction. Studies conducted with persons listening to speech or pure tones in noise suggest, however, that for normal-hearing persons in noise levels above 80 dB, ear muffs are probably not detrimental to the above listening task.

INTRODUCTION

Noise represents a particular problem for personnel who work in ships' engine and boiler rooms. Unless the propulsion and auxiliary-machinery controls are located in sound-treated areas, individuals standing watch at these stations are exposed to moderately high levels of noise. At the Engine Room console and at the port work table of HMCS TERRA NOVA, for example, sound pressure levels range from 85 to 100 dBA; at the Boiler Room console and at the burner attendant's position, sound pressure levels range from 82 to 94 dBA (Crabtree and Forshaw, 1974).

In Canadian Forces 280-class destroyers, on the other hand, control and monitoring equipment is located in a relatively quiet area (typically 69 dBA) away from the main machinery spaces. Consequently, the engine and auxillary machinery rooms need only to be occupied during normal watchkeeping rounds, cleaning and maintenance operations, or during special times such as light-off of the engines (Crabtree, 1975).

Marine Engineering Technicians are responsible for the operation of the main engines of the ships in the Canadian Forces, and for the maintenance, repair and modifications to the main and auxiliary boilers. An attitude survey of a sample of Canadian Forces Marine Engineering Technicians has indicated that 40 per cent of these polled were bothered by the noise in engine and boiler rooms, and another 50 per cent, although not bothered by the noise "could not hear sounds that they should hear", because of the noise (Innes and McFadden, 1974).

An analysis of audiometric data has shown, moreover, that the incidence of hearing loss among Marine Engineering Technicians places the trade in the second highest hearing-loss-risk group (of five risk groups) in the Canadian Forces (Forshaw, 1973). After 11 to 15 years of military service, for example, 30 per cent of the group (compared with 25 per cent of all Canadian Forces personnel) have incurred a hearing loss in excess of 30 dB in at least one ear in the frequency range between 3000 and 8000 Hz.

When it is not possible to control noise at its source, the most expedient method of reducing its effects upon hearing is by means of personal protection devices. It is generally believed by engine and boiler room personnel, however, that the noise attenuation provided by an effective ear muff or earplug will adversely affect their ability to detect by ear those sounds that indicate real or potential machinery malfunction. Hence, there is considerable reluctance to wear such protection.

This reluctance is not unique to Canadian Forces Marine Engineering

Technicians. In spite of the known hazards of noise exposure to hearing, the use of protection devices is more or less universally unpopular. Exceptions occur, of course, in situations where noise levels are sufficiently high to produce feelings of apprehension, discomfort or pain, or where noise attenuating ear muffs with earphones are necessary for reliable voice communication.

In some instances, objections to ear protectors are not unreasonable. Ear muffs can be uncomfortable after long periods of wearing, and the ears become hot and perspire beneath them[1]. To be effective, earplugs must be a reasonably snug fit and usually produce some discomfort.

Many workers who wear hearing protection on a regular basis report that normal voice communication is made difficult. In areas where the ability of a worker to hear warning signals is regarded as important, ear muffs and earplugs have indeed been considered a hazard to safety.

THE EFFECT OF HEARING PROTECTION ON VOICE COMMUNICATION IN NOISE

Kryter (1946) was the first of many (Pollack, 1957; Williams, Forstall and Parsons, 1970; Acton, 1967; Howell and Martin, 1975) to investigate the effect of hearing protection devices upon speech reception. The study was conducted in reverberent conditions using a noise spectrum and method of presenting the speech stimuli (by loudspeaker) to simulate the acoustic environment encountered in the engine room of a submarine. Kryter notes, in fact, that the acoustic conditions used in his study are similar to those found in many industrial and military situations. His results show that in noise levels that mask (elevate) a threshold for hearing speech by 80 dB or more, the use of earplugs such as the V-51R should not decrease speech intelligibility.

Most recently, Howell and Martin (1975) have shown that wearing hearing protection can have varying effects upon speech reception, depending on the type of protection worn and the noise conditions. Below 70 dB, for example, a person wearing ear muffs or plugs (providing 25-35 dB attenuation in the speech-frequency range) is likely to experience a reduction in received speech intelligibility, due to the fact that the less intense segments of speech are reduced to inaudible levels. Hearing protection is not normally required at levels below 85 dB. Above 85 dB, however, wearing a hearing protector while

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[1] In the engine and boiler rooms of Canadian Forces ships, the temperature is considered to be uncomfortable by 50 per cent of the Marine Engineering Technicians surveyed by Innes and McFadden (1974).

listening to speech from a loudspeaker will not cause a reduction in speech intelligibility, and in fact, may result in an improvement in intelligibility to the extent that the hearing protector reduces distortion because of overloading in the auditory system. Aural harmonics are produced in the cochlea at levels above about 65 dB, and this distortion increases with increasing sound pressure level.

On the other hand, when a hearing protection device is worn by a talker in noise, his vocal effort is reduced to the extent that a listener experiences a reduction in intelligibility due to the decreased signal-to-noise ratio. A normal hearing talker unconsciously regulates the intensity of his own voice according to the acoustic environment. In noise, he automatically raises his vocal effort to compensate for the masking effect of the noise on his perceived voice level. But if a talker wears a hearing protector and thereby prevents the noise in the environment from reducing the perceived loudness of his own voice relative to the noise, he will not be forced to expend the extra vocal effort and will reduce the level of his speech received by others. Likewise, when protectors are worn by both talker and listener, the composite effect is an overall reduction in intelligibility.

Howell and Martin further showed that the intelligibility of received speech in noise was two or three per cent less when wearing ear muffs than when wearing earplugs. They speculate that since the attenuation provided by ear muffs is greater than that provided by earplugs in the 1000-to 4000-Hz frequency range, ear muffs attenuate relatively more of the energy contained in the consonant sounds (crucial for speech discrimination) than do earplugs.

The authors note, moreover, that persons with appreciable hearing loss will not benefit (in terms of received speech intelligibility) from wearing ear muffs or earplugs in noise as much as do those with normal hearing. The effect of a given hearing protector upon such a person's ability to communicate in noise, or detect a signal, will depend on the attenuation characteristics of the protector, the spectrum of the noise, and the degree and type of hearing loss (Kryter, 1970).

LISTENING TO PURE TONES IN NOISE WITH EAR MUFFS

The question remains: Is an individual, listening for those sounds in machinery noise that signal a real or potential malfunction, at a disadvantage while wearing hearing protection?

Because it has not been possible to quantify sufficiently the cues that engine room personnel listen for, it is difficult to resolve this question with confidence on the basis of the known per-

ceptual capabilities of the human auditory system. For although this listening task must certainly involve the detection of signals in noise, it also requires at least some sort of discrimination between, and/or recall and recognition of, a number of complex tonal patterns.

A controlled laboratory investigation of the problem, to have any validity, should simulate both the acoustic conditions of the engine-room environment and the important characteristics of the sound stimuli produced by a malfunctioning machine. Moreover, the experimental observers should be trained so that their ability to detect these auditory cues relates to that of experienced engine-room personnel. In discriminating complex tonal patterns, experienced listeners appear to discriminate between stimuli they have encountered previously, or which they expect or are directed to look for, more accurately than they do with stimuli that are unexpected or unfamiliar (Watson et al, 1976).

In spite of these restrictions, two experiments were conducted to at least determine whether wearing Canadian Forces standard issue ear muffs affected an observer's ability to detect a pure-tone stimulus in noise. Both studies were carried out in a reverberant chamber; the noise and pure-tone stimulus were presented from loudspeakers.

The continuous-spectrum noise in the engine rooms of Canadian Forces IRE-class destroyers is mainly low frequency, depending on the ship's speed, type of auxiliary equipment in operation, and measurement location. The octave-band sound pressure levels at the engine room console of HMCS TERRA NOVA (ship's speed = 14 kts, turbo alternator operating) are 80, 86, 79, 85, 83, 84, 80, 75, 73 dB in the octave bands from 31.5 Hz to 8000 Hz (Crabtree and Forshaw, 1974). In addition, strong line components are produced by the main gear boxes, turbines, compressors, alternators, etc. With increased propeller shaft rpm, gear noise becomes more dominant, resulting in intense spectrum peaks in the 500- and 2000-Hz octave bands (Crabtree and Forshaw, 1974).

Accordingly, the background noises used in the above experiments were generated electronically (using a constant spectrum-density noise generator and spectrum shaper, or a series of pure-tone oscillators) to simulate at the observer's position in the reverberation chamber (Experiment 1) the continuous-spectrum noise described above (88 dBA) without line components, or (Experiment 2) the most intense line components (460 Hz (69 dB), 855 Hz (79 dB), 1750 Hz (59 dB), 1850 Hz (79 dB), 2240 Hz (81 dB), and 2560 Hz (80 dB)), without background continuous-spectrum noise, encountered in the previously described engine room.

The task of the observer was simply to indicate by push button in which of two stimulus-intervals, indicated by cue lights, a pure tone was presented. The stimulus intervals, lasting .25 seconds, were separated by a .5 second interval. The response logic was enabled at the start of the next stimulus interval, and remained so until the start of the next stimulus sequence (2.75 seconds later) or until a response button was pushed by the subject. The control logic accepted the first response made by the observer, and if the response was correct, gave immediate feedback in the form of a "correct response" light.

The experimenter monitored the correct and incorrect responses, and using a one-decibel step attenuator, adjusted the level of the pure-tone stimulus according to a modified PEST (parameter estimation by sequential testing) procedure (Taylor and Creelman, 1966). The aiming point of all PEST trials was 80 per cent correct.

On a given day, an observer was tested in one of the above masking noises at one stimulus frequency only. Three pairs of PEST runs were made, each pair consisting of a trial with ear muffs and a trial without. The observer was permitted to rest for at least ten minutes between pairs of runs. In Experiment 1, the order of the conditions (i.e., wearing or not wearing ear muffs) was alternated from one pair of PEST runs to another. In Experiment 2, where the line-spectrum masking noise was much more stressful, at least subjectively[2], the trial with ear muffs always preceded the trial without in order to minimize any effect that the three- to five-minute unprotected noise exposure might otherwise have on the next trial.

Three normal-hearing observers (hearing threshold levels not exceeding 20 dB at the test-stimulus frequencies) were used in Experiment 1. Each was tested twice (on separate days) at each frequency. The results of their trials (in relative thresholds) are shown in Figures 1 to 6. In each graph, the region within one standard error is represented by the vertical bars, indicating the reliability of the measures.

The results of Experiment 1 (using the octave-band continuous-spectrum noise previously described) are summarized as follows: Observer 1 (Figures 1 and 2) showed generally better performance with ear muffs at 1000, 3000, 4000 and 6000 Hz. Observer 2 (Figures 3 and 4) performed marginally better with ear muffs at some frequencies. Observer 3 (Figures 5 and 6) showed better performance

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[2] Although temporary threshold shifts were not found, the observer in Experiment 2 noted a "feeling of fullness in his ears" after a number of PEST runs.

with ear muffs at 1000, 1500, 2000 and 6000 Hz. At no frequencies were any of the three observers significantly handicapped ($p < .05$) by wearing ear muffs.

A fourth observer, having a moderately severe bilateral sensorineural hearing loss (see Figure 7) participated in Experiment 1 at five test frequencies. At 500, 1000, 2000 and 6000 Hz (see Figure 8), there was no significant difference ($p > .05$) in performance between wearing and not wearing ear muffs. At 3000 Hz, however, this observer could not hear the pure tone at its maximum possible intensity in the noise while wearing ear muffs. With the masking noise off, in fact, the 3000 Hz tone had to be increased to within 10 dB of its maximum possible intensity to be heard with ear muffs.

Because of the severity of the noise used in Experiment 2 (the pure-tones previously described) only one observer (the author) was used. Each test frequency was repeated three times on separate days. The results (see Figures 9 to 11) indicate that at 1500 Hz, on the first and third days, and at 2000 Hz on the second day, performance was significantly better ($p < .01$) when not wearing ear muffs. In spite of the generally wide but mixed day-to-day differences observed at all other frequencies tested, the differences between wearing and not wearing ear muffs were not significant ($p > .05$).

The experiment was repeated at 1500 Hz with the line-spectrum masking 10 dB more intense than previous. The results (see Table I) again showed mixed but smaller differences between wearing and not wearing ear muffs, which at this higher level, were not statistically significant ($p > .05$). In this phase of the experiment, slight temporary threshold shifts were observed at 3000 and 4000 Hz (about 10 and 15 dB respectively) on each of the three days after completion of the third pair of PEST runs.

It may be concluded from the above, based on very limited data, that normal hearing observers are probably not significantly handicapped by ear muffs when detecting pure tones in continuous-spectrum noise, at least at levels above 85 dBA. Indeed, at some frequencies, their performance may improve with muffs.

However, individuals with bilateral hearing losses will be adversely affected by ear muffs if the attenuation of the device reduces the level of the signal below their threshold.

The ability of an observer to detect a pure tone in a background of a number of other tones may be significantly reduced at some frequencies when ear muffs are worn in ambient levels at or below 80 dB. This performance decrement probably disappears,

however, as the intensity of the background tones increases above 80 dB.

SUMMARY

It is acknowledged that the question of whether individuals listening for machinery malfunctions in noise are at a disadvantage while wearing hearing protection has not been resolved directly.

In protecting the ears of persons standing watch in engine rooms, one is attempting, of course, to reduce the incidence and severity of noise-induced temporary and permanent hearing loss. Clinically, it is well known that severe sensorineural hearing pathologies are often accompanied by such effects as non-linear growth in the sensation of loudness, distortion (either unilateral or bilateral) of the sensation of pitch, and speech discrimination impairments (Glorig, 1965; Rose, 1971).

It is not unreasonable to suppose, therefore, that persons suffering from one or more of these effects may be handicapped to a greater or lesser extent than might normal hearing individuals listening for machinery malfunctions with ear muffs, if one assumes for the moment that ear muffs are indeed detrimental to this task.

Based on the findings of studies conducted with persons listening to speech in noise, and to a lesser degree, on the results derived from the puretone experiments reported herein, one is led to conclude, however, that for normal hearing persons in noise levels above 80 dB, ear muffs are probably not detrimental to the above listening task.

RECOMMENDATIONS

Newly recruited Canadian Forces personnel entering the Marine Engineering Technician trade and having H1 hearing categories should, on a trial basis, commence and continue their training for steam and/or gas-turbine qualifying certificates wearing ear muffs when working in noise hazardous areas. Since there are no on-shore billets for such training, all instruction must be on-the-job training while students and instructors carry out their regular duties (Innes and McFadden, 1974).

DCIEM would welcome the opportunity to monitor the effect of wearing ear muffs upon watch keeping proficiency in the above program by conducting a number of case studies on new Marine Engineering Technicians as they progress through the above phase of their training.

ACKNOWLEDGEMENT

The author wishes to thank Mrs. C.D. Couture for her invaluable assistance during the running of this investigation.

TABLE I

Relative threshold (in dB) of 1500-Hz pure tone, masked by simulated line-spectrum engine-room noise.

	RELATIVE THRESHOLD WITHOUT EAR MUFF	RELATIVE THRESHOLD WITH EAR MUFF
Day 1.		
Mean	15.7 dB	17.7 dB
Standard Error	.7 dB	1.8 dB
Day 2.		
Mean	13.0 dB	12.3 dB
Standard Error	1.15 dB	2.8 dB
Day 3.		
Mean	14.7 dB	12.7 dB
Standard Error	.9 dB	.9 dB

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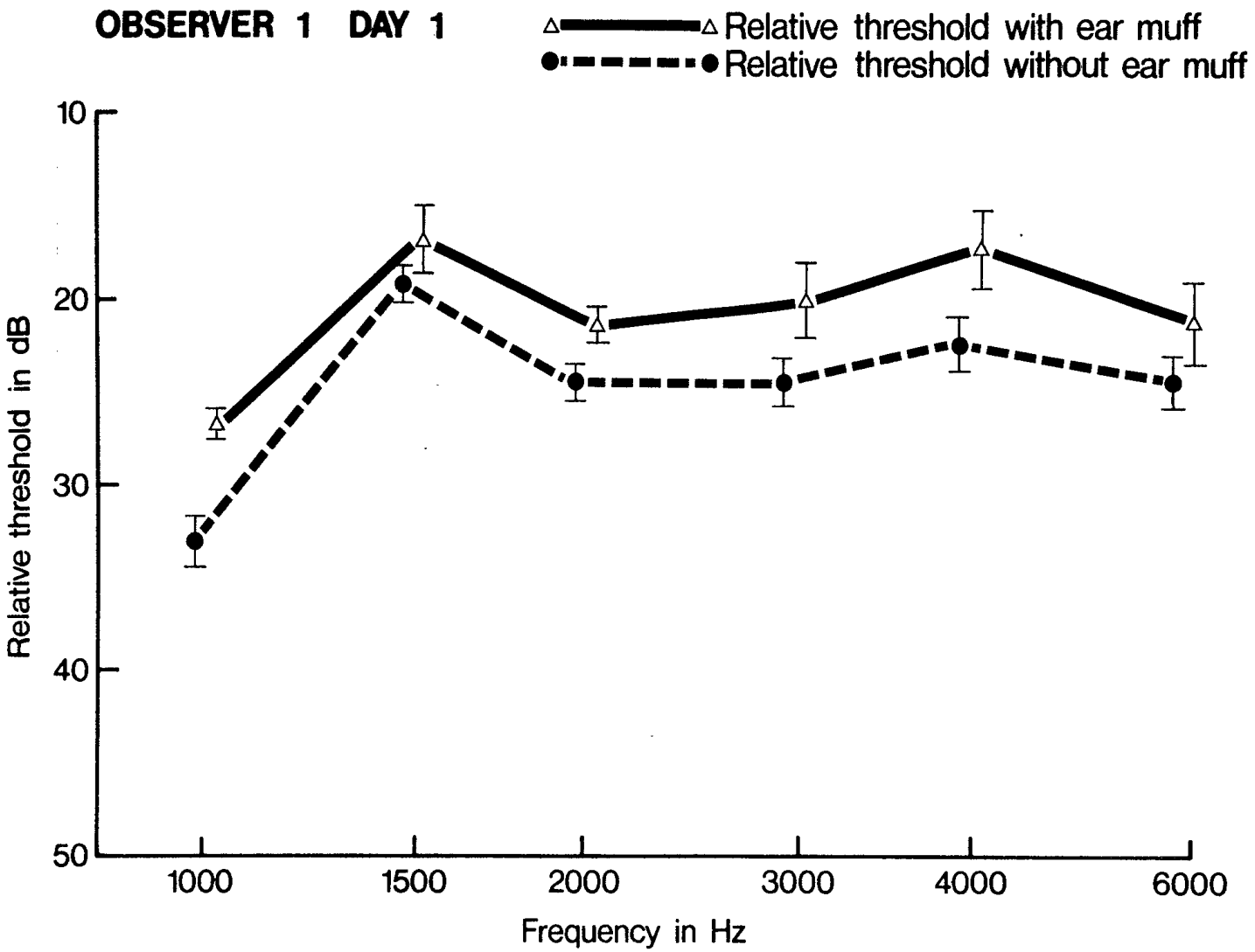

Figure 1. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 1 on day 1 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

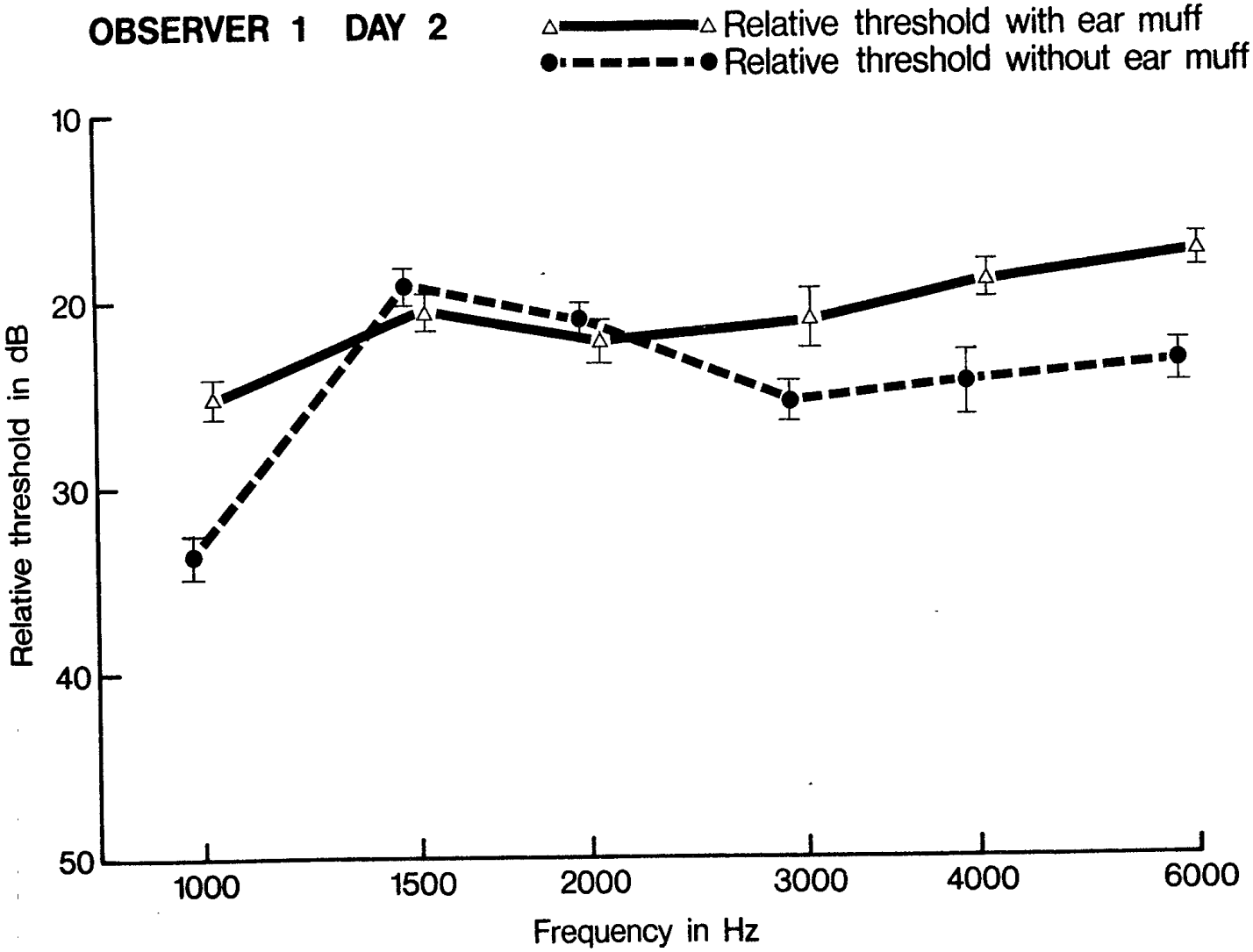

Figure 2. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 1 on day 2 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

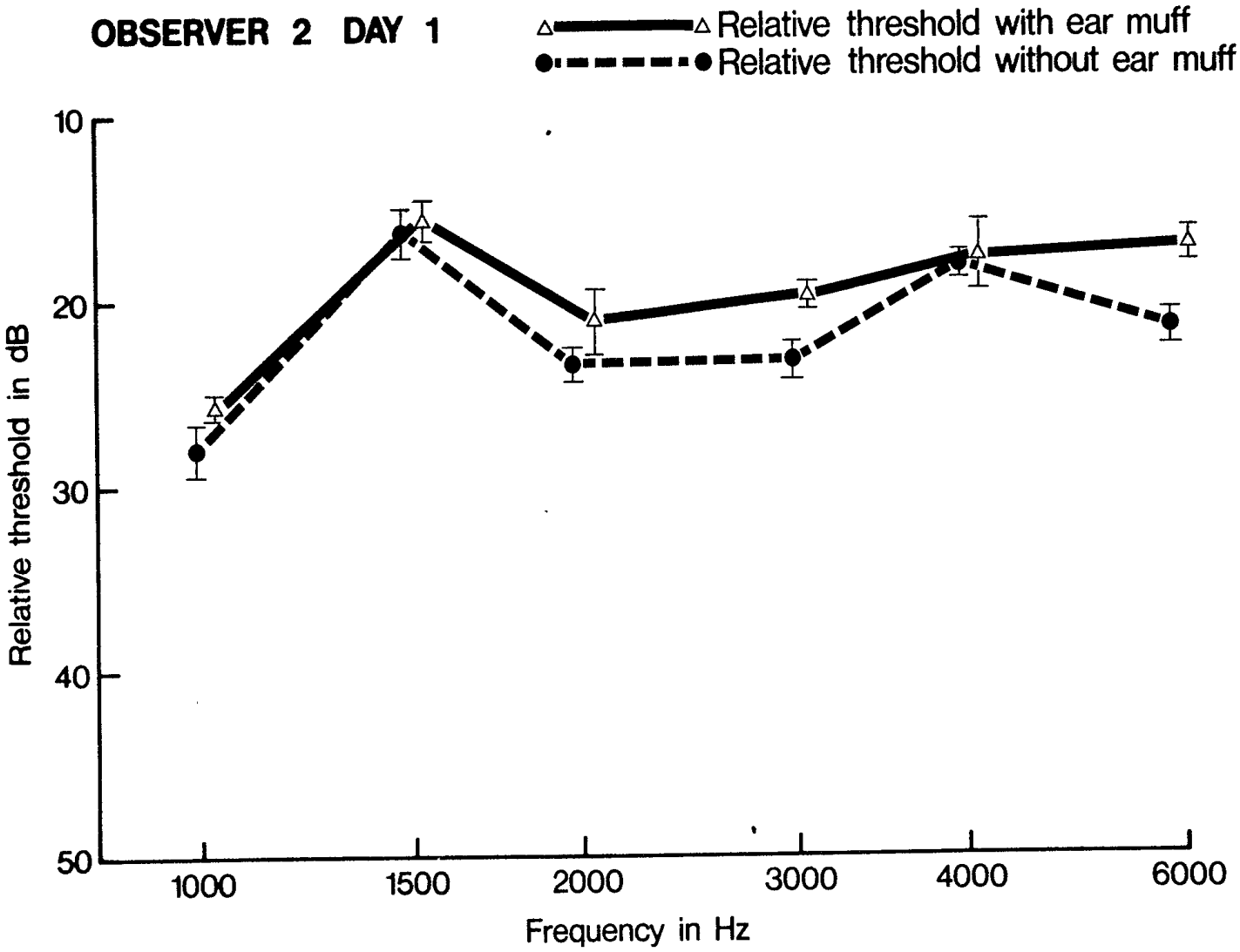

Figure 3. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 2 on day 1 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

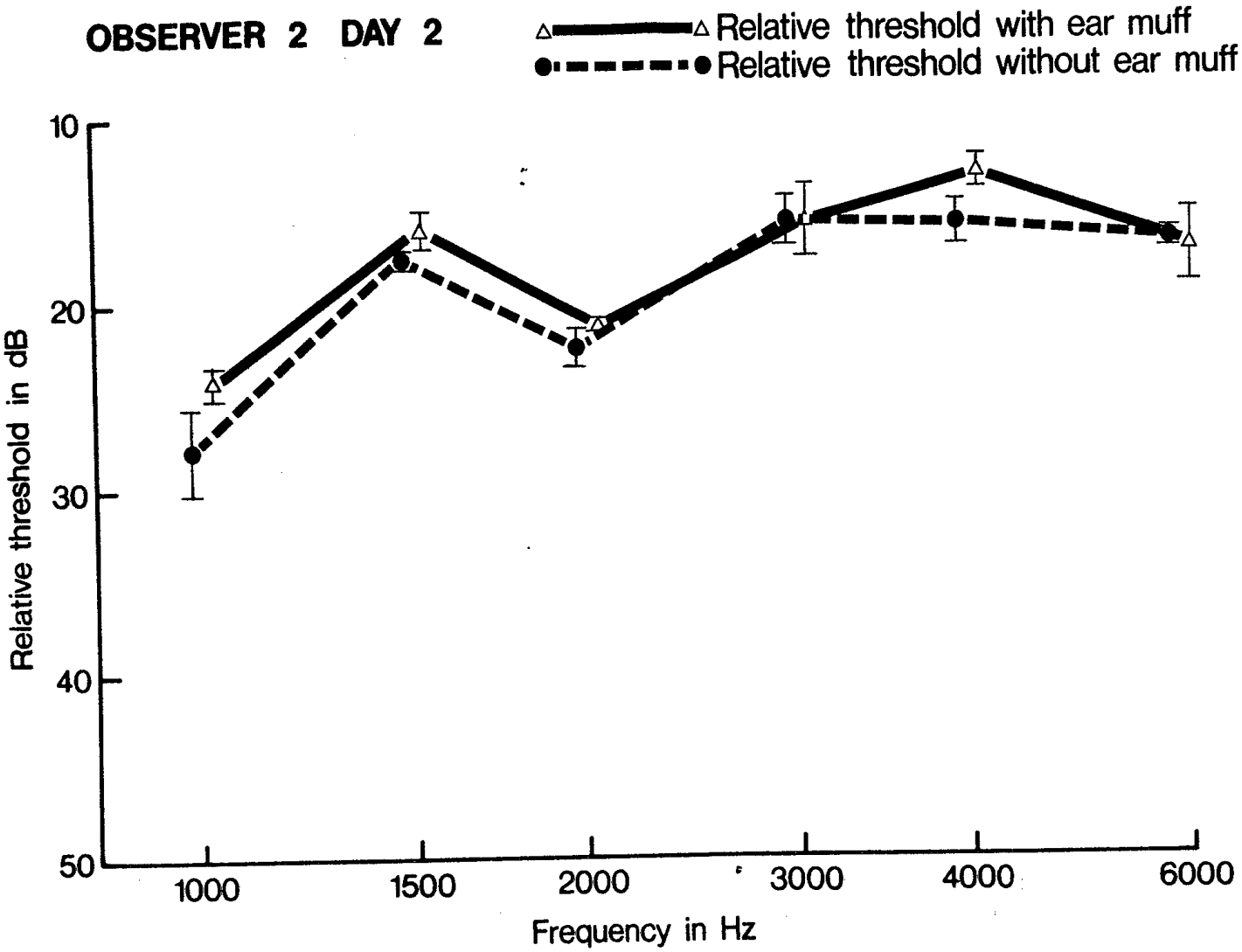

Figure 4. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 2 on day 2 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

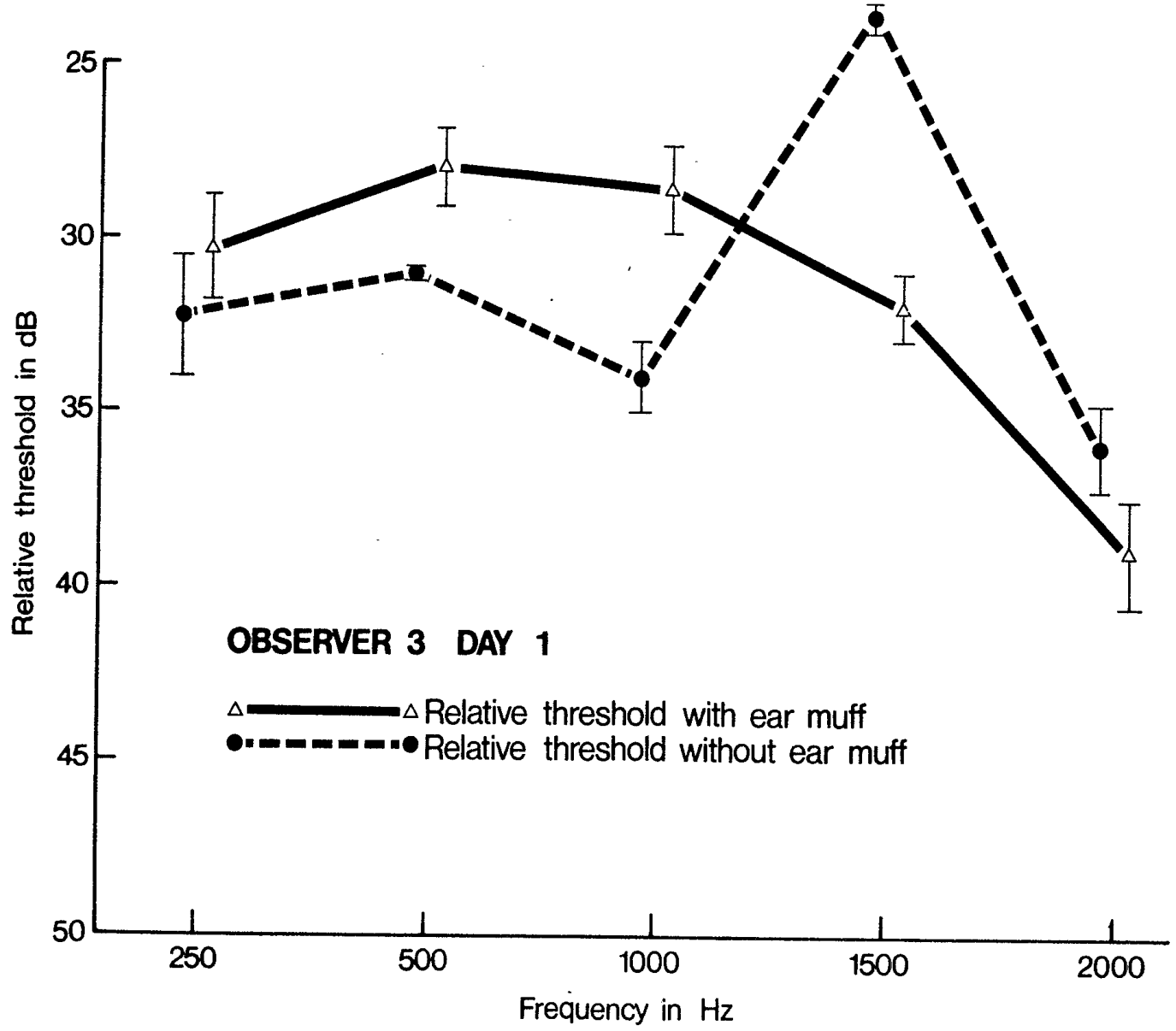

Figure 5. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 3 on day 1 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

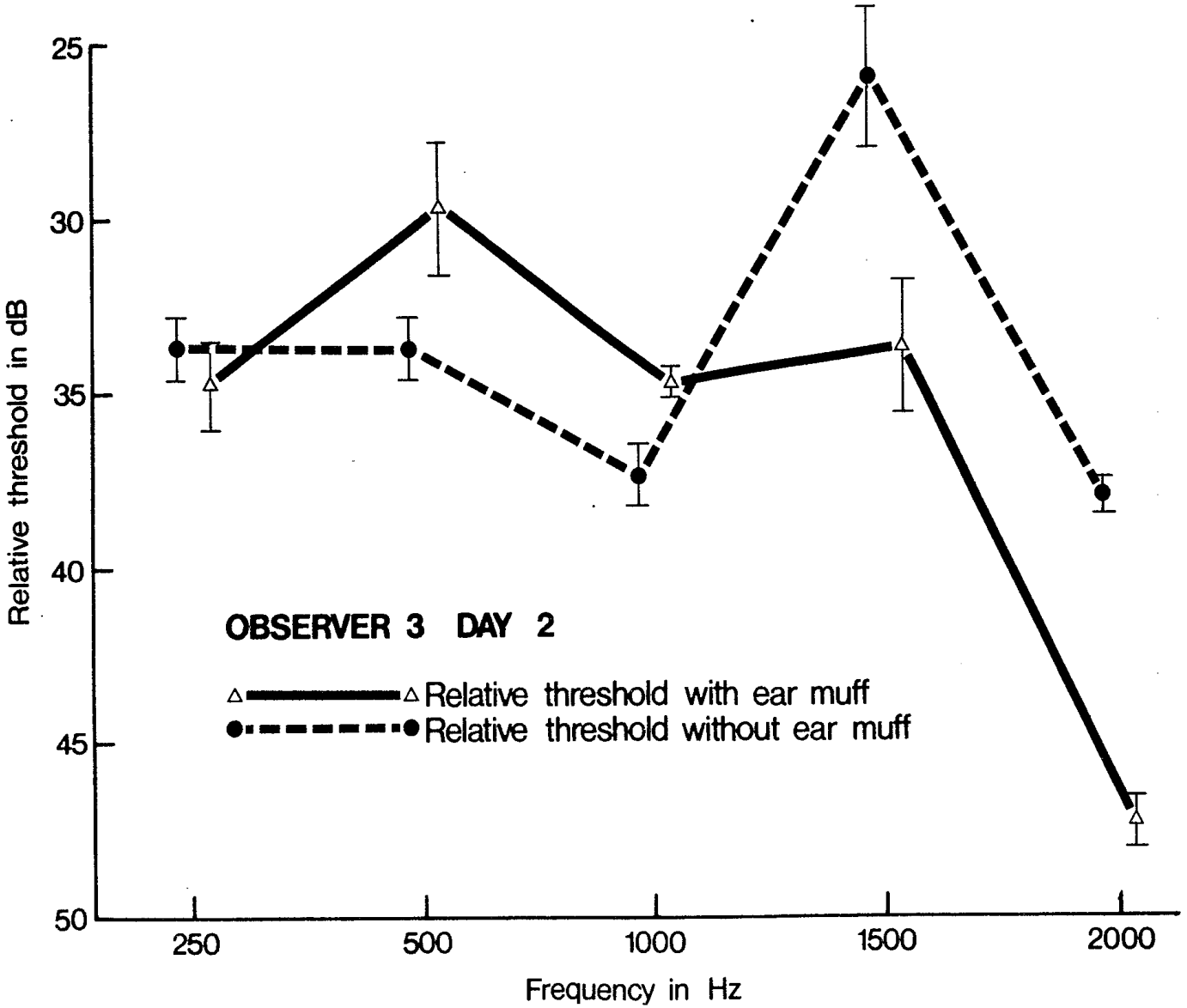

Figure 6. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 3 on day 2 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

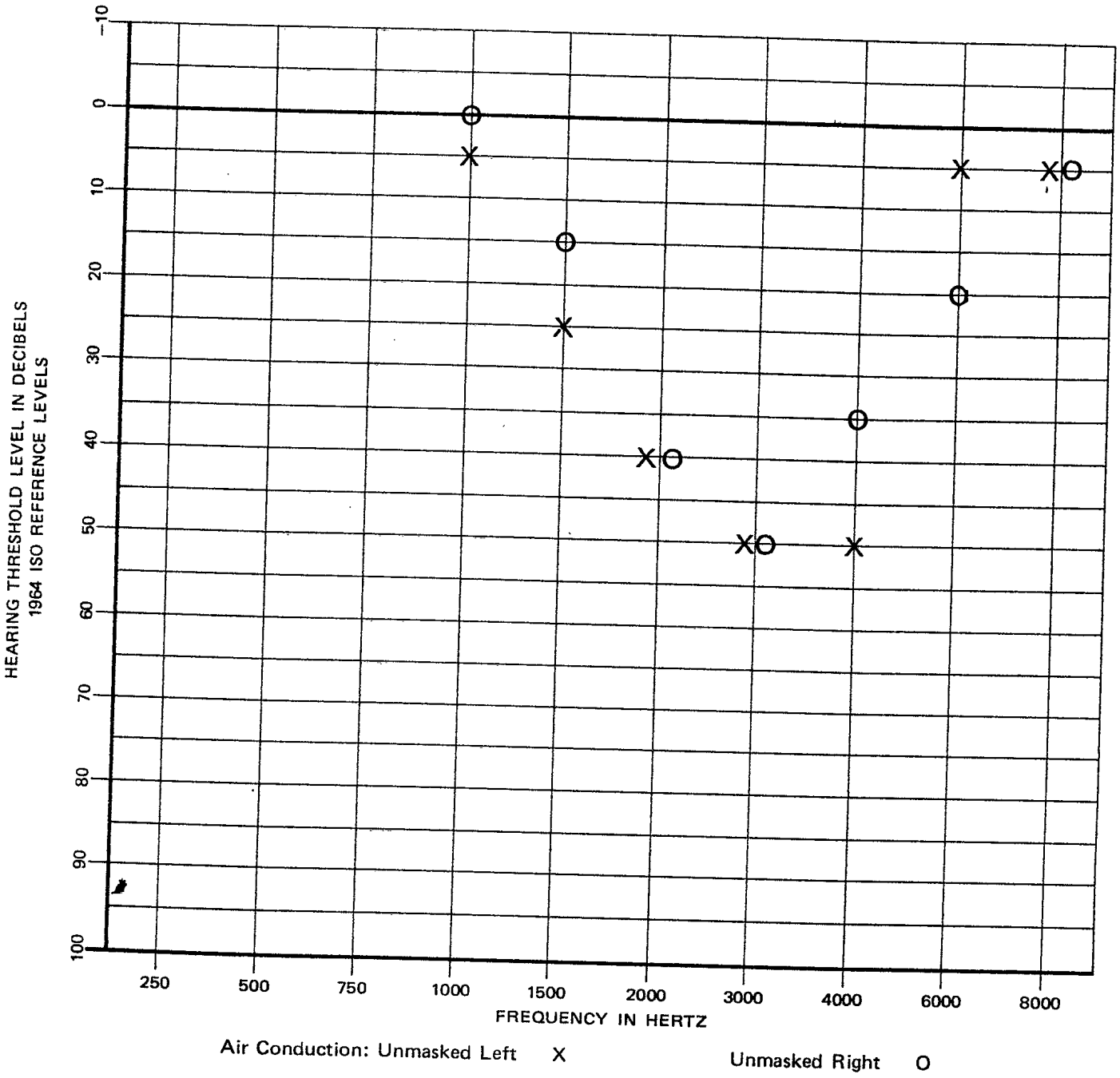

Figure 7. Pure-tone air-conduction threshold levels of the fourth observer, indicating a moderately severe bilateral sensorineural loss.

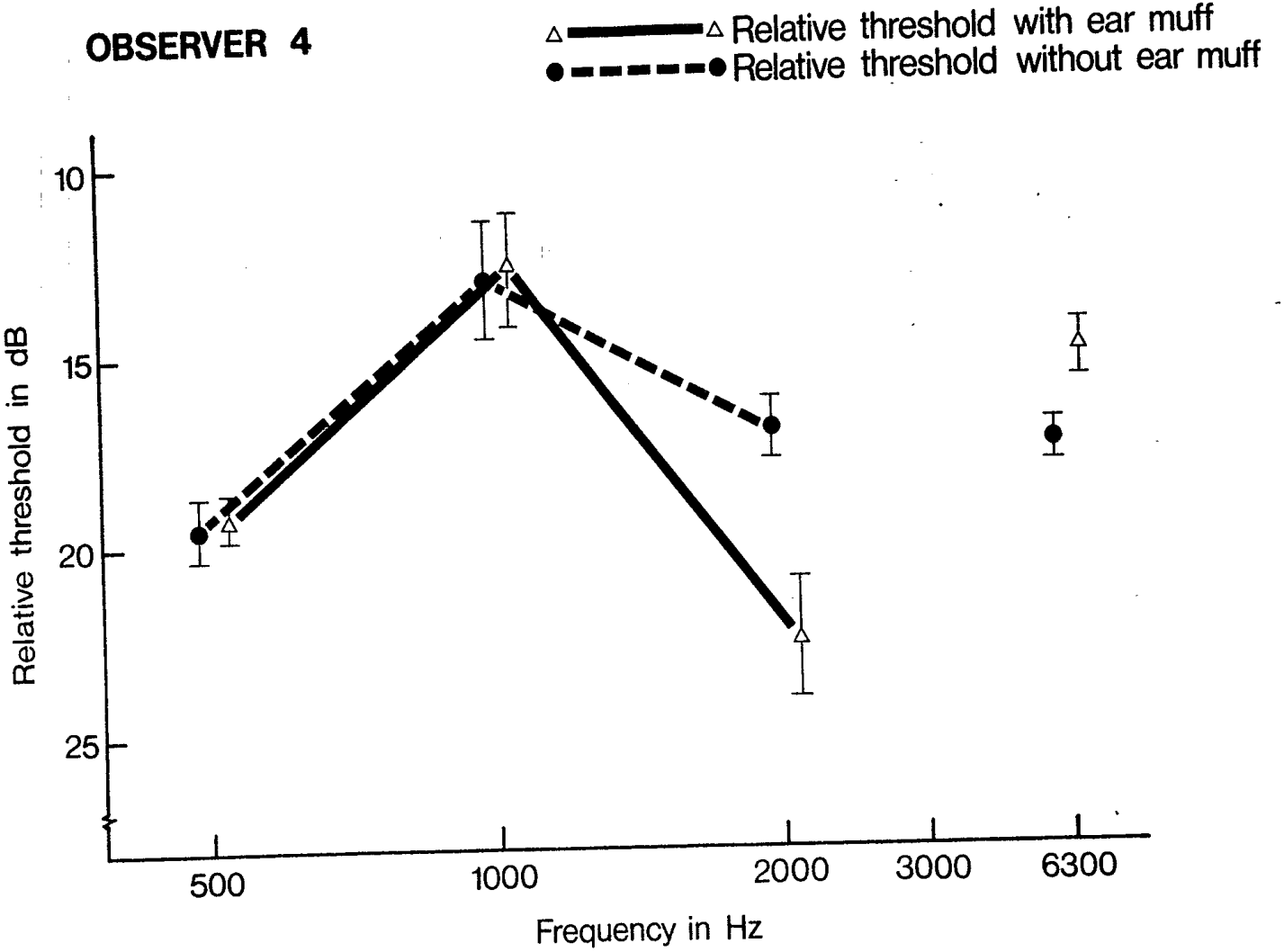

Figure 8. Relative thresholds in dB for pure tones, masked by simulated continuous-spectrum engine-room noise, for observer No. 4 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

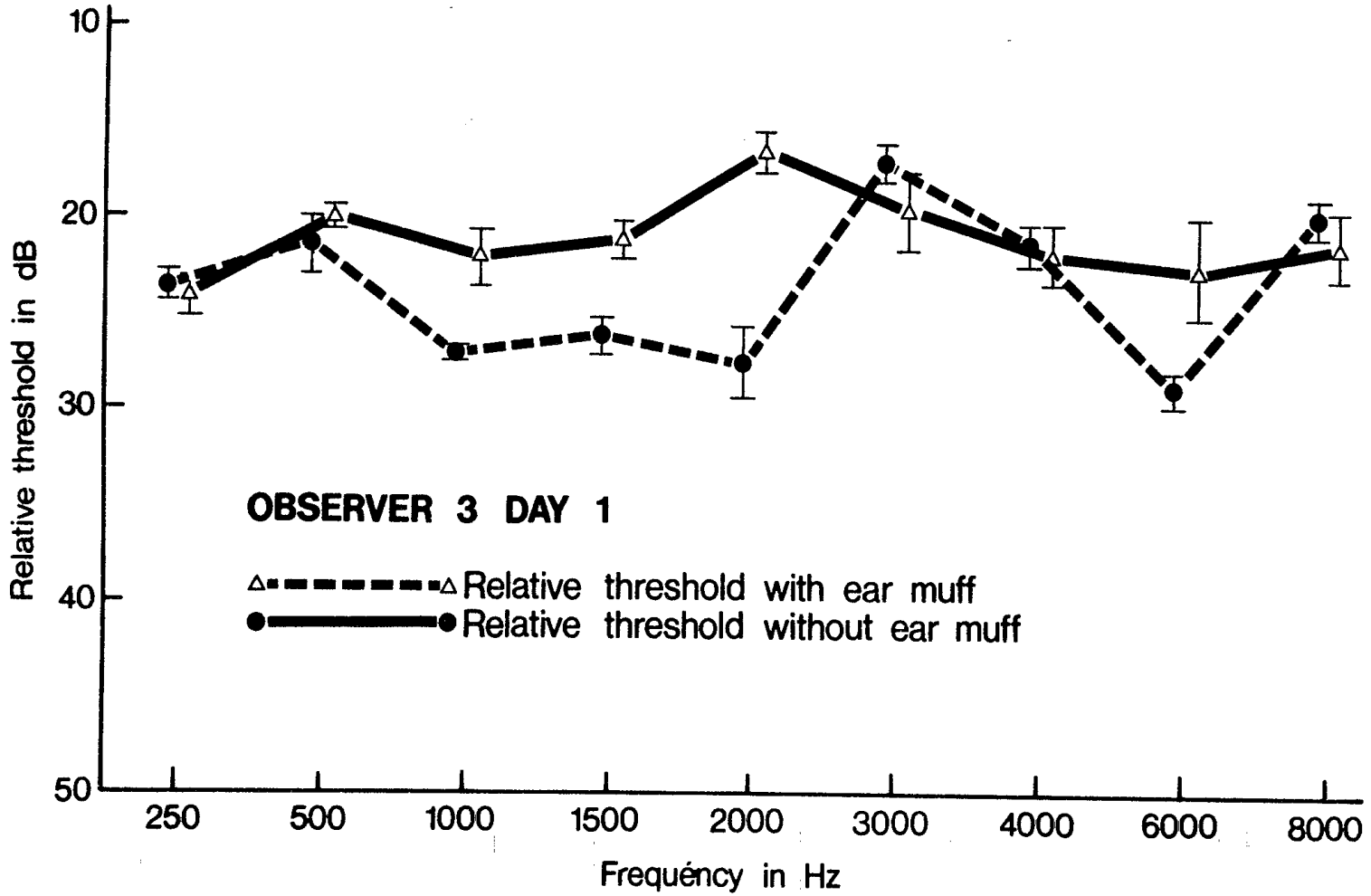

Figure 9. Relative thresholds in dB for pure tones, masked by simulated line-spectrum engine-room noise, for observer No. 3 on day 1 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

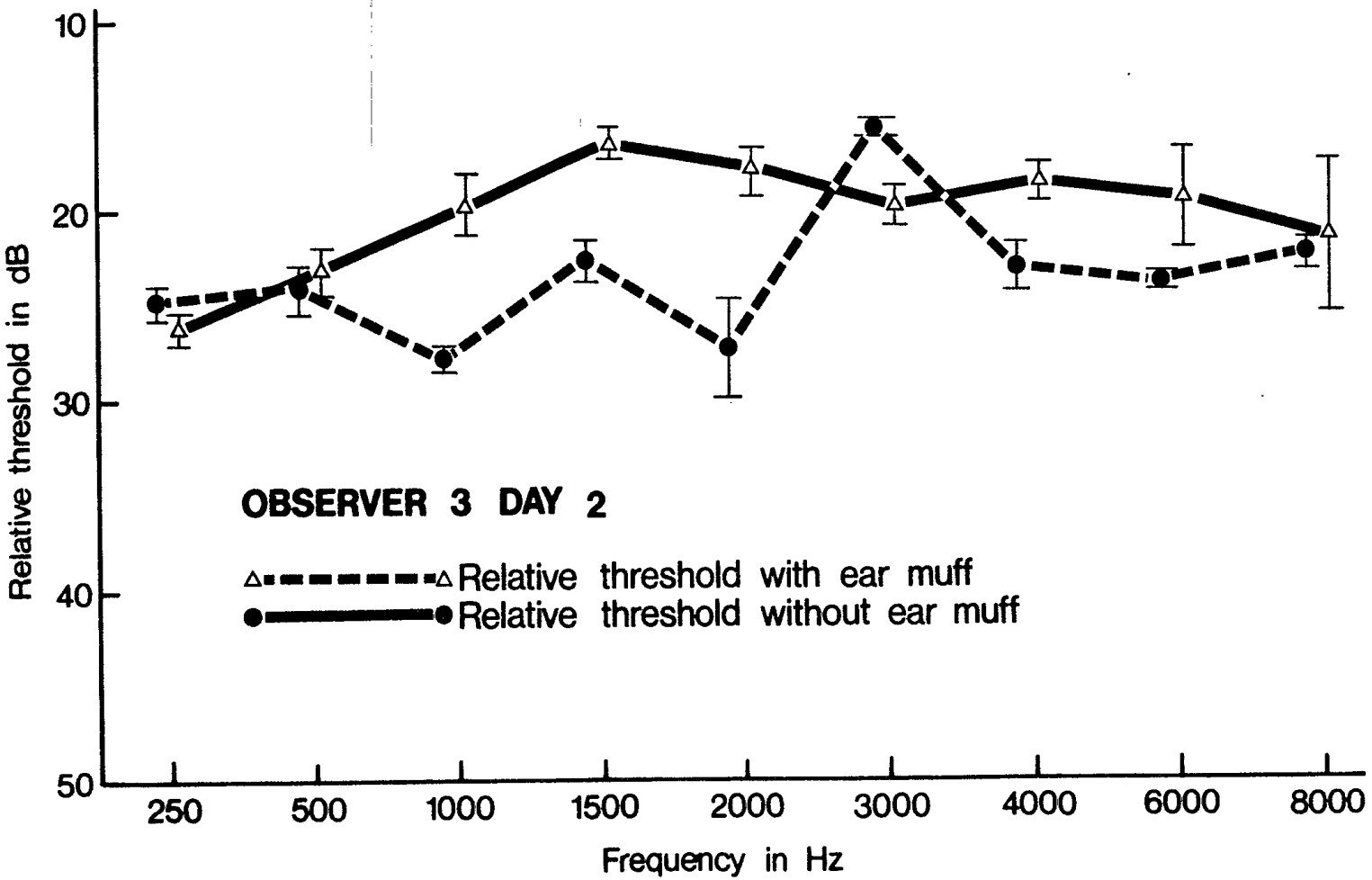

Figure 10. Relative thresholds in dB for pure tones, masked by simulated line-spectrum engine-room noise, for observer No. 3 on day 2 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

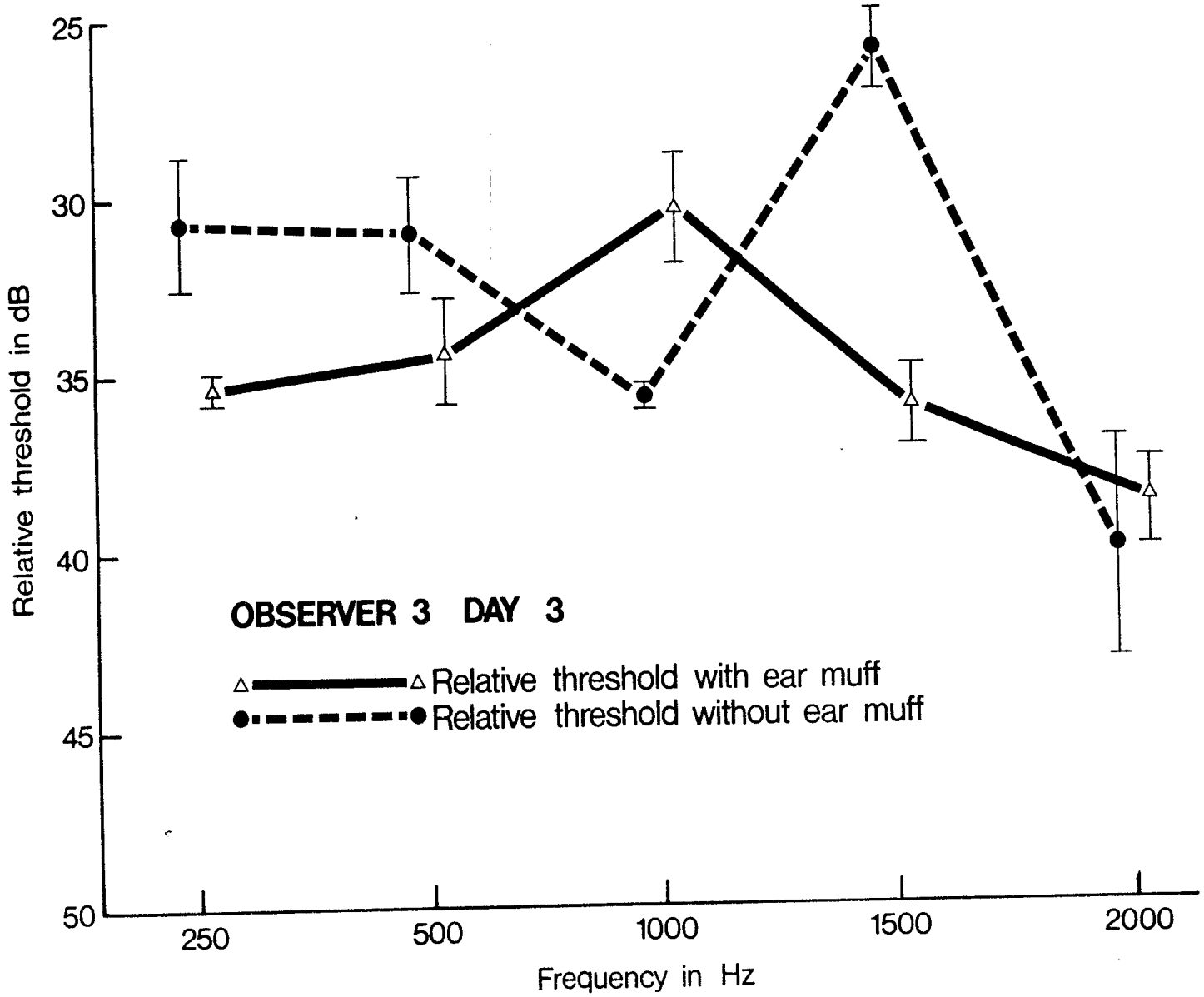

Figure 11. Relative thresholds in dB for pure tones, masked by simulated line-spectrum engine-room noise, for observer No. 3 on day 3 (3 trials). The vertical bars represent one standard error above and below the mean threshold. Note that the data points are offset slightly along the frequency axis to facilitate comparison of the standard errors of the two curves.

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