# HUMAN FACTORS, 1990, 32(1), 9-25<br>Attenuation Performance of Four Hearing Attenuation Performance of Four Hearing Protectors under Dynamic Movement and Different User Fitting Conditions HUMAN FACTORS, 1990, 32(1), 9–25<br>Attenuation Performance of Four Hearing<br>Protectors under Dynamic Movement and<br>Different User Fitting Conditions<br>JOHN G. CASALI<sup>1</sup> and MIN-YONG PARK, *Virginia Polytechnic Institute and Stat* AN FACTORS, 1990, 32(1), 9–25<br>
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16. CASALI<sup>1</sup> and MIN-YONG PARK, *Virginia Polytechnic Institute and State*<br> *xsity,*

University, Blacksburg, Virginia

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An experiment was conducted to determine the effects of movement activities and<br>
alternative fitting procedures on protection levels afforded by f forty, *BlacksBurg*, *Vrigmia*<br>An experiment was conducted to determine the effects of movement activities and<br>alternative fitting procedures on protection levels afforded by four hearing pro-<br>tection devices (HPDs). Psyc An experiment was conducted to determine the effects of movement activities and<br>alternative fitting procedures on protection levels afforded by four hearing pro-<br>tection devices (HPBs). Psychophysical attenuation measureme An experiment was conducted to determine the effects of movement activities and alternative fitting procedures on protection levels afforded by four hearing protection devices (HPDs). Psychophysical attenuation measurement An experiment was conducted to determine the effects of movement activities a<br>laternative fitting procedures on protection levels afforded by four hearing p<br>tectroin devices (HPDs). Psychophysical attenuation measurements allowed during the wearing period. Ine subject-til conductor resulted in signin-<br>andly lower protection levels, from 4 to 14 dB, at 1000 Hz and both or a pre-<br>moled golymer carping, a user-molded foam earplug, and a double Example the method in the solution in the solution of the solution of the state of the following of a multiple of the following of a multiple in the multiple method for the following of a multiple method of the presentient y fit the protectors according to either<br>t fit) or after receiving interactive train-<br>r no further protector adjustments were<br>unjeint-fit condition resulted in signifi-<br>4 dB, at 1000 Hz and below for a pre-<br>foam earplug, a r fit) or after receiving interactive train-<br>
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in frequency-specific ubject-tit condition resulted in signiti-<br>4 dB, at 1000 Hz and below for a pre-<br>foam earplug, and a double protector<br>The muff alone was significantly more<br>than were the plugs. Movement activity<br>in frequency-specific attenu

### Hearing Loss Countermeasures

INTRODUCTION intensity sounds of industrial, military, or <sup>4</sup> dB, at 1000 H2 and below tor a pre-<br>foam earplug, and beaule protector<br>The muff alone was significantly more<br>than were the plugs. Movement activity<br>in frequency-specific attenuation over<br>numf-plug combination. The comp band captury, and a coutor protector<br>The muff alone was significantly more<br>than were the plugs. Movement activity<br>in frequency-specific attenuation over<br>muff-plug combination. The compliant<br>over type of movement effect but non man wore the plugs. Movement activity<br>han were the plugs. Movement activity<br>in frequency-specific attenuation over<br>nuff-plug combination. The compliant<br>r type of movement effect but did ben-<br>f the trained-fit procedure in frequency-specific attenuation over<br>in frequency-specific attenuation over<br>nuff-plug combination. The compliant<br>r type of movement effect but did ben-<br>fthe trained-ift procedure. Implications<br>ig protocol, device selecti nuff-plugcombination. The compliant<br>r type of movement effect but did ben-<br>the trained-fit procedure. Implications<br>g protocol, device selection, and user<br>meritarity sounds of industrial, military, or<br>even recreational ori

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HUM.<br>1987), spectators of noisy activities such as and motivated subjects a<br>1987), spectators of noisy activities such as and motivated subjects a<br>automobile racing, and consumers who use a very short wearing per<br>new, prop sonnel.

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tection Agency estimates (EPA, 1981), this re-<br>
quirement affects more than 9.2 million NRR overestimated protection in the field by<br>
American workers, including military pe quirement affects more than 9.2 million NRR overestimated protection in the field by<br>American workers, including military per-<br>an average of 13 dB or greate, depending on<br>Sonnel. The Problem of Rating Hearing the standard American workers, including military per-<br>
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thereof, are the p Spectral attenuation data and the noise re-<br>about 10–35 dB, 13 dB of protection overes-<br>duction rating (NRR), which is computed timation is quite significant, especially if the<br>duction rating (NRR), which is computed tima duction rating (NRR), which is computed timation is quite significant, especially if the chereof, are the primary metrities by which one ambient noise is above 100 dB(A) and a mar-<br>chan predict whether or not HPDs will pro

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(B(A) or greater be supplied with HPDs the surveys of Lempert and Edwards (1983)<br>
(OSHA, 1983), Based on Environmental Proton Parallelia (1976). Berger (1983a HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>and motivated subjects are seated quietly for<br>a very short wearing period and tested with<br>new, properly fit HPDs under optimal condi-<br>tions. In contrast, in the field workers may<br>wear ill-fitted and/or damage HUMAN FACTORS<br>
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HPDs are tseted and raded for attenuation are<br>
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the laboratory-obtained attenuation values<br>
i Firms are tested and rated for attenuation are<br>quite different from those in the environ-<br>ments where HPDs are actually used. As such,<br>the laboratory-obtained attenuation values<br>indicate significantly higher protection tha dicate significantly higher protection than<br>typically attained in the field, as verified by<br>e surveys of Lempert and Edwards (1983)<br>dd Padilla (1976). Berger (1983a) concluded<br>the basis of a review of studies that the<br>RR o is typically attained in the field, as verified by<br>is typically attained in the field, as verified by<br>the surveys of Lempert and Edwards (1983)<br>and Padilla (1976). Berger (1983a) concluded<br>on the basis of a review of stud The surveys of Lempert and Edwards (1983)<br>the surveys of Lempert and Edwards (1983)<br>and Padilla (1976). Berger (1983a) concluded<br>on the basis of a review of studies that the<br>NRR overestimated protection in the field by<br>an and Padilla (1976). Berger (1983a) concluded<br>on the basis of a review of studies that the<br>NRR overestimated protection in the field by<br>an average of 13 dB or greater, depending on<br>the standard deviation adjustment applied on the basis of a review of studies that the<br>NRR overestimated protection in the field by<br>an average of 13 dB or greater, depending on<br>the standard deviation adjustment applied to<br>the calculation. When one considers that t

### Research Objective

thereof, are the primary metrics by which one ambient noise is above 100 dB(A) and a mar-<br>can predict whether or not HPDs will provide ginal protector is used.<br>
adequate protection and OSHA compliance<br>
in a given high-nois NRR overestimated protection in the field by<br>an average of 13 dB or greater, depending on<br>the standard deviation adjustment applied to<br>the calculation. When one considers that the<br>range of NRRs for currently available, sta an average of 13 dB or greater, depending on<br>the standard deviation adjustment applied to<br>the calculation. When one considers that the<br>range of NRRs for currently available, stan-<br>dard (i.e., non-level-dependent) HPDs is<br>a the standard deviation adjustment applied to<br>the calculation. When one considers that the<br>range of NRRs for currently available, stan-<br>dard (i.e., non-level-dependent) HPDs is<br>about 10–35 dB, 13 dB of protection overes-<br>ti the calculation. When one considers that the<br>range of NRRs for currently available, stan-<br>dard (i.e., non-level-dependent) HPDs is<br>about 10–35 dB, 13 dB of protection overes-<br>timation is quite significant, especially if th range of NRRs for currently available, stan-<br>dard (i.e., non-level-dependent) HPDs is<br>about 10–35 dB, 13 dB of protection overes-<br>timation is quite significant, especially if the<br>ambient noise is above 100 dB(A) and a mardard (i.e., non-level-dependent) HPDs is<br>about 10–35 dB, 13 dB of protection overes-<br>timation is quite significant, especially if the<br>ambient noise is above 100 dB(A) and a mar-<br>ginal protector is used.<br>Research Objective<br> about 10–35 dB, 13 dB of protection overes-<br>timation is quite significant, especially if the<br>ambient noise is above 100 dB(A) and a mar-<br>ginal protector is used.<br>Research Objective<br>The intent of this study was to develop a timation is quite significant, especially if the<br>ambient noise is above 100 dB(A) and a mar-<br>ginal protector is used.<br>Research Objective<br>The intent of this study was to develop and<br>utilize a laboratory-based protocol to es notion to is above 100 dB(A) and a mar-<br>nal protector is used.<br>Search Objective<br>The intent of this study was to develop and<br>ilize a laboratory-based protocol to esti-<br>ate the influence of two important vari-<br>les (HPD fitti

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HEARING PROTECTION<br>
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Riko, 1982; Casali and Epps, 1986; Casali and and Grenell (1989) measured HEARING PROTECTION<br>
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Riko, 1982; Casali and Epps, 1986; Casali and and Grenell (1989) measured attenuation<br>
Lam, 1986) have indicated that the attenuation for each after subjects performed a Riko, 1982; Casali and Epps, 1986; Casali and and Grenell (1989) measu<br>Lam, 1986) have indicated that the attenua-<br>fore and after subjects pe<br>tion achieved may be dependent on how the sembly task for approxim<br>subject was

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that work-related and aw movement may de-<br>
the multigromomy of them utilized<br>
that were intended to represent the extremes a simulation of highly kinematic, strenuous<br>
of fittin multips). For this study two fitting conditions grade attenuation, but none of them utilized<br>the distribution typically encountered by work activity, in which hearing protector at<br>fitting instruction typically encountered that were intended to represent the extremes a simulation of highly kinematic, strenuous<br>hof fiftting instruction typically encountered by work activity, in which hearing protector at-<br>the industrial workers were compared by thiting instruction typically encountered by<br>
which hearing protector at<br>
the industrial workers were compared. These tenuation may be most likely to degrade to<br>
included naive-subject fit (*subject fit*) using critica The industrial workers were compared. These tenuation may be most likely to degrade to<br>hardly anive-subject fit (subject fit) using critical levels. Therefore, to provide a con-<br>nly HPD package instructions and trained-tr included naive-subject iit (*subject* iii) using critical levels. Therefore, to provide a consumptional movement than the activity is transfer to the activity strations and trained fill using HPD package in- ity variable, by D package instructions and trained trolled, repeatable investigation of the active<br>istiperior for the HFD wearing period in his<br>structions as well as close supervision by a study consisted of either a vigorous, who<br>lesubject it (*tramed jti*) using HPD package in- ity variable, the HPD wearing period in this<br>disturctions as well as close supervision by a study consisted of either a vigorous, whele-<br>trained experimenter. body physica structions as well as close supervision by a trady consisted of enter a vigorous, whole-<br>trained experimenter.<br>
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movement activity. Of p Framed experimentarion contents to the positival work activity or temporoman-<br>
Another important field influence is worker dibular movement activity elicited by chew-<br>
movement activity. Of particular relevance to ing mov Another important littel trithlence is worker dibutal movement activity eliterate and forced on the performance of earplugs are temporo-<br>movement activity. Of particular relevance to ing movements and forced vocal efforts movement activity. Up particular relevance to ing movements and torced vocal eftorts.<br>
We performance of earplugs are temporo-<br>
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plugs th the pertormane of earning are temporal and the pertormane of earning and the pertormane of earning the moleculo the moleculo the pertormane pertor of earning the pertormane pertormane pertormane and its custom-molecule or mand outlier (jaw) movements induced by<br>
the wearing gum or tobacco, eating, or talking<br>
while wearing HPDs on the job. For most ear-<br>
Forty paid volunteer subjects participated,<br>
ments are limited (with the exception of EVERTIFY BY THE UNITE SURFAINTS (SURFAINTS) Are the moved and point of the subjects while wearing HPDs on the job. For most ear-<br>plugs the data on temporomandibular move-<br>Forty paid volunter subjects participated,<br>plugs t while wearing HPPS on the Joo. Formost example the participated,<br>when the data on temporomandibular move<br>free over forty paid volunteer subjects participated,<br>ments are limited (with the exception of slow-with five males plugs ine eara on temporomanulous move-<br>
Forty paid volutiner subjects participated.<br>
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mecovery foam plugs, which demonstrate assigned to each of four HPD conditions. The<br>
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subject group had the following character Excessive control and prings, winter a sumpred assumed to each of our HPD conducts. In<br>this or no change), but large amounts of jaw subject group had the following characteris-<br>movement have generally resulted in reduced t Extreme to moment the generally resulted in reduced<br>tincs:<br>throwcement have generally resulted in reduced tics:<br>protection (Abel and Rokas, 1986; Berger,<br>protection (Abel and Rokas, 1986; Berger,<br>definitive for work-relate

February 1990—11<br>Riko, 1982; Casali and Epps, 1986; Casali and and Grenell (1989) measured attenuation be-<br>Lam, 1986) have indicated that the attenua-<br>fore and after subjects performed a light as-<br>tion achieved may be depe February 1990—11<br>
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quency. Those studies gen iser HPDs (are<br>plugs the presentive to root but only at the lowest (1225 Hz) test tre-<br>the more strongly influenced by user instruc-querey. Those studies generally pointed out<br>tion than is that of circumaural HPDs (ear-<br>th be more strongly influenced by user instruct querely. Those studies generally pointed out the model and Robas in the model and Robas in the model and Robas in the formula of the model and the model of represent the extrem February 1990—11<br>sured attenuation be-February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>and Grenell (1989) measured attenuation be-<br>fore and after subjects performed a light as-<br>sembly task for approximately 1.25 hr while<br>wearing Willson 665 earmuffs. A slight drop<br>in attenuation occurred ove February 1990—11<br>
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ariable, the HPD vearing period in this<br>
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#### METHOD

### Subjects

tics: udy consisted of either a vigorous, whole-<br>oldy physical work activity or temporoman-<br>bular movement activity elicited by chew-<br>g movements and forced vocal efforts.<br>METHOD<br>bigets<br>for the males and five females randomly<br>si Physical work activity or temporoman-<br>
physical work activity or temporoman-<br>
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must males and five females randomly<br> physical work activity or temporoman-<br>ar movement activity elicited by chew-<br>novements and forced vocal efforts.<br>METHOD<br>ezts<br>were made to each of four HPD conditions. The<br>ect group had the following characteris-<br>age range bular movement activity elicited by chew-<br>g movements and forced vocal efforts.<br>METHOD<br>thects<br>Society pure-tone and five-females randomly<br>signed to each of four HPD conditions. The<br>biject group had the following characteri movements and forced vocal efforts.<br>
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- with tive males and tive temales randomly<br>assigned to each of four HPD conditions. The<br>subject group had the following characteris-<br>ics:<br>(1) age range of 19–35 years, mean age of fe-<br>males = 23.1 years, of males = 24.6 ye assigned to each of four HFD conditions. The<br>subject group had the following characteris-<br>tics:<br>(1) age range of 19–35 years, or males = 28.16 years;<br>males = 23.1 years, or males = 24.6 years;<br>corresponds the attenuation i

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### Apparatus

12—February 1990 HUMAN FACTORS<br>
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Apparatus chamber having ambient octave-band noise<br>
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HUMAN FACTORS<br> *Apparatus* chamber having ambient octave-band noise<br> *levels of less* than 10 dB (linear) at center fre-<br> *freal-car* attenuation at threshold) data were dB at 125 Hz, and 12—February 1990 HUMAN FACTORS<br>
HUMAN FACTORS<br> *Apparatus* chamber having ambient octave-band noise<br> *Attenuation test instrumentation*. All REAT quencies from 250 to 8000 Hz and less than 14<br>
freal-car attenuation at thr Free the state of 5 (1960) and the state of the state and tracing a Békésy (1960) psychophysi- test sign 12—February 1990 HUMAN FACTORS<br>
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damber having ambient octave-band noise<br>
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collected using a Békésy (1960 **EXECUTE:** The measure and the state of the state of learning and the there and the difference of the state and the state of the s *leteruation test instrumentation*. All REAT *all* evers of tess than 10 del (linear) at center the<br>creal-ear attenuation at threshold) data were dB at 125 Hz, and a reverberation time for all<br>collected using a Békkey (196 Atternation test tratification. All NEAT quences from 220 to 8000 Hz and less than 24<br>circal-ear attenuation at threshold) data were dB at 125 Hz, and a reverberation time for all<br>collected using a Békésy (1960) psychophy Ireal-ear attenuation at threshold) data were<br>collected using a Békésy (1960) psychophysi-test signal frequencies less than 0.20 s. Cali-<br>cal procedure in which the subject pressed a bration was verified daily with a Lars collected using a Bekesy (1960) psychopysi-test signal frequencies less than 0.20 s. Calindre attenuation whenever a signal was audible Davis 800-B one-third-octave analyzer and carricol causing it to decrease in 1-dB step cal procedure in which the subject pressed a bration was veritted daily with a Larson-<br>tontrol button whenever a signal was addible Davis 800-B one-third-octave analyzer and<br>(causing it to decrease in 1-dB steps at an at-A control button wenever a signal was audible Davis Solv-B one-linre-ockave analyzer and<br>(causing it to decrease in 1-dB steps at an at-ACO 7013 microphone. The hearing protector<br>tenuator rate of 5 dB/s) and released the but (causing It To decrease in 1-a0 steps at an at-NO (701) merophone. Lee nearing protector<br>tenuator rate of 5 dB/s) and released the but-test facility has been verified to be in accor-<br>ton whenever the signal was inaudible enuator rate of 2 dusy) and reaesed the but- test fitcultly has been vertical to be in accor-<br>ton whenever the signal was inaudible (caus-<br>dance with ANSI S12.6-1984 (Casali, 1988).<br>Ing it to increase at the same rate). I ton wmere the signal was maturone (cause canne with a succe wind a state. The content of the subject tracked the threshold for each test trial tasks were performed by the occluded the subject tracked the threshold for each Even to the series of peak and valley reversals interchangeable manual on the tracing for each test frequency. Békésy motor shaft, each of six tracings were obtained (protector off) con- riod. All activities were producted tor worn) and unoccluded (protector off) con-<br>
for tor worn) and unoccluded (protector off) con-<br>
food. All activities were paced with a<br>
ditions for each subject, and the difference (in nome, and physical workload was co

third-octave noise bands, with center fre- minute), load pushing (50 per minute), and<br>quordies of 125, 250, 500, 1000, 2000, 2000, 2150, bar (shoulder) rotation (50 rotations per<br>4000, 6300, and 8000 Hz, pulsed on-off at

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dB at 125 Hz, and a reverberation time for all<br>
test signal freque

mg it to increase at ims and rate). In elect  $\sim$  work as equipment. Sot simulated musi-<br>the subject tracked the threshold for each test trial tasks were performed by the occluded<br>frequency, producing a tracing of thresho Entertations for tensions of vacantest train tensis we bettomine so the controllation of the experimentation of the threshold subject, who worked in a constant 28°C enviresponse on a computer monitor. Using a ronnent. A m response on a computer motion. Using a vonment. A motorized work task similator<br>response on a computer monitor. Using a vonment. A motorized work task similator<br>computer scoring algorithm, the threshold (Figure 1) provided Expense of a computer scoring algorithm, the threshold (Figure 1) provided calibrated resistance<br>for each frequency was computed as the mid-against which the subject had to work. Using<br>point of the series of peak and walle Example the series of peak and all the subset of the state of the the tracing for each test frequency. Bekkey motor shaft, each of six different activities<br>the tracing for each test frequency. Bekkey motor shaft, each of six different activities<br>reings were obtained for occluded (procetracings were obtained for occluded (protec-<br>vas performed during each work activity pe-<br>or worn) and uncocluded (protec-<br>vas performed during each work activity pe-<br>or worn) and uncocluded (protecor of) con- riod. All act ditions for each subject, and the difference (in nome, and physical workload was controlled<br>
dBB) between the occluded and unoccluded using constant resistance from the simulator.<br>
dtreshbolds was taken as the attenuation dB) between the occluded and unoccluded using constant resistance from the simulator.<br>
thresholds was taken as the attenuation pro- These activities (with pacine hesses)<br>
threds by the HPD for a given test frequency. cons thresholds was taken as the attenuation pro-<br>These activities (with pacing in parentheses)<br>characted by the HPD for a given test frequency. consisted of valve turning (50 leftright half-<br>disch time an attenuation test was duced by the HPD for a given test frequency. consisted of valve turning (50 left/right half-<br>Each time an attenuation test was taken in turns per minute), ladder climbing (100 runs<br>Berbare match and the experimental seque Each time an attenuation test was taken in turns per minute), ladder climbing (100 rungs<br>the experimental sequence, separate thresh-<br>perminute), crowbar work (50 pushipulal sper<br>blok were obtained for each of nine one- mi the experimental sequence, separate thresh-<br>per minute), crowbar work (50 push/pulls per<br>olds were obtained for each of nine one- minute), straight lever pulling (70 cycles per<br>third-octave noise bands, with center fre- m olds were obtained for each of nine one-<br>minute), straight lever pulling (70 cycles per minute), load pushing (50 per minute), load pushing (50 per minute), control<br>durations of pulling (50 per minute), load pushing (50 pe chamber having ambient octave-band noise<br>levels of less than 10 dB (linear) at center fre-<br>quencies from 250 to 8000 Hz and less than 24<br>dB at 125 Hz, and a reverberation time for all<br>test signal frequencies less than 0.20 chamber having ambient octave-band noise<br>levels of less than 10 dB (linear) at center fre-<br>quencies from 250 to 8000 Hz and less than 24<br>dB at 125 Hz, and a reverberation time for all<br>test signal frequencies less than 0.20 chamber having ambient octave-band noise<br>levels of less than 10 dB (linear) at center fre-<br>quencies from 250 to 8000 Hz and less than 24<br>dB at 125 Hz, and a reverberation time for all<br>test signal frequencies less than 0.20 chamber having ambient octave-band noise<br>levels of less than 10 dB (linear) at center fre-<br>quencies from 250 to 8000 Hz and less than 24<br>dB at 125 Hz, and a reverberation time for all<br>test signal frequencies less than 0.20 rivels of less than 10 dB (linear) at center tre-<br>quencies from 250 to 8000 Hz and less than 24<br>dB at 125 Hz, and a reverberation time for all<br>test signal frequencies less than 0.20 s. Cali-<br>bration was verified daily with quencies from 250 to 8000 Hz and less than 24<br>dB at 125 Hz, and a reverberation time for all<br>test signal frequencies less than 0.20 s. Cali-<br>bration was verified daily with a Larson-<br>Davis 800-B one-third-octave analyzer a dB at 125 Hz, and a reverberation time tor all<br>test signal frequencies less than 0.20 s. Cali-<br>bration was verified daily with a Larson-<br>Davis 800-B one-third-octave analyzer and<br>ACO 7013 microphone. The hearing protector<br> test signal frequencies less than 0.20 s. Calibration was verified daily with a Larson-<br>Davis 800-B one-third-octave analyzer and<br>ACO 7013 microphone. The hearing protector<br>test facility has been verified to be in accor-<br>d bration was veritied daily with a Larson-<br>Davis 800-B one-third-octave analyzer and<br>ACO 7013 microphone. The hearing protector<br>test facility has been verified to be in accor-<br>dance with ANSI S12.6-1984 (Casali, 1988).<br>Work Davis 800-B one-third-octave analyzer and<br>ACO 7013 microphone. The hearing protector<br>test facility has been verified to be in accor-<br>dance with ANSI S12.6-1984 (Casali, 1988).<br>Work task equipment. Six simulated indus-<br>tria ACO 7013 microphone. Ine nearing protector<br>test facility has been verified to be in accor-<br>darner with ANSI S12.6-1984 (Casali, 1988).<br> $Work task equipment. Six simulated influss-  
trial tasks were performed by the occluded  
subject, who worked in a constant 28°C envi-  
ronment. A motorized work task similar  
(Figure 1) provided calibrated resistance  
against which the subject had to work. Using  
interchangingable manual control heads on the  
motor shaft, each of six different$ rest racinty has been vertited to be in accor-<br>dance with ANSI S12.6-1984 (Casali, 1988).<br>Work task equipment. Six simulated indus-<br>trial tasks were performed by the occluded<br>subject, who worked in a constant 28°C envi-<br>ro Work task equipment. Six simulated indus-<br>Work task equipment. Six simulated indus-<br>trial tasks were performed by the occluded<br>subject, who worked in a constant 28°C envi-<br>ronment. A motorized work task similator<br>(Figure 1 *work lask were* performed by the occluded<br>trial tasks were performed by the occluded<br>subject, who worked in a constant 28°C envi-<br>ronment. A motorized work task similator<br>(Figure 1) provided calibrated resistance<br>against trare tasks were priorinted by the octrude<br>subject, who worked in a constant  $28^{\circ}$  environment. A motorized work task similator<br>(Figure 1) provided calibrated resistance<br>against which the subject had to work. Using<br>int supect, who worked in a constant 2c curve.<br>Tromment. A motorized work task similator<br>(Figure 1) provided calibrated resistance<br>against which the subject had to work. Using<br>interchangeable manual control heads on the<br>mort s Chinetic. The motion of the distinct work and similated resistance (Figure 1) provided calibrated resistance against which the subject had to work. Using interchangeable manual control heads on the motor shaft, each of six is a gains the mean cance can<br>against which the subject had to work. Using<br>interchangeable manual control heads on the<br>motor shaft, each of six different activities<br>was performed during each work activity pe-<br>riod. All ac symon to use a consideration that we have the respect that the motor shaft, each of six different activities was performed during each work activity period. All activities were paced with a metro-nome, and physical workloa motor shaft, each of six different activities<br>motor shaft, each of six different activities<br>was performed during each work activity pe-<br>riod. All activities were paced with a metro-<br>nome, and physical workload was controll was performed during each work activity pe-<br>was performed during each work activity pe-<br>riod. All activities were paced with a metro-<br>nome, and physical workload was controlled<br>using constant resistance from the simulator. ing constant resistance from the simulator.<br>
nese activities (with pacing in parentheses)<br>
nsisted of valve turning (50 left/right half-<br>
rms per minute), ladder climbing (100 rungs<br>
r minute), crowbar work (50 push/pulls These activities (with pacing in parentheses)<br>consisted of valve turning (50 left/right half-<br>turns per minute), ladder climbing (100 rungs<br>per minute), crowbar work (50 push/pulls per<br>minute), straight lever pulling (70 c consisted of valve turning (50 left/right half-<br>turns per minute), ladder climbing (100 rungs<br>per minute), crowbar work (50 push/pulls per<br>minute), straight lever pulling (70 cycles per<br>minute), load pushing (50 per minute turns per minute), ladder climbing (100 rungs<br>per minute), crowbar work (50 push/pulls per<br>minute), straight lever pulling (70 cycles per<br>minute), load pushing (50 per minute), and<br>bar (shoulder) rotation (50 rotations per per minute), crowbar work (50 push/pulls per<br>minute), straight lever pulling (70 cycles per<br>minute), load pushing (50 per minute), and<br>bar (shoulder) rotation (50 rotations per<br>minute). Concurrent with this work task, subminute), straight lever pulling (70 cycles per<br>minute), load pushing (50 per minute), and<br>bar (shoulder) rotation (50 rotations per<br>minute). Concurrent with this work task, sub-<br>jects were required to turn their head and<br>n minute), load pushing (50 per minute), and<br>bar (shoulder) rotation (50 rotations per<br>minute). Concurrent with this work task, sub-<br>jects were required to turn their head and<br>neck approximately 100 deg every 5 s to mon-<br>tor

### Experimental Design and Protocol

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Figure 1. An occluded subject performing a work task activity; monitoring video displays are located in the<br>rear. Shown is the valve rotation activity, one of six activities using the Baltimore Therapeutic Equipment Work Simulator.

Figure 1. An occluded subject performing a work task activity; monitoring video displays are located in the pear. Shown is the value rotation activity, one of six activities using the Baltimore Therapeutic Equipment work Figure 1. An occluded subject performing a work task activity; monitoring video distants.<br>
Figure 1. An occluded subject performing a work task activity; monitoring video distants work Simulator.<br>
Work Simulator.<br>
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- seal<br>(3) F-A-R "IlltraFit" Plug (NRR = 27): a pre-

(4) Combination: Bilsom muff over E-A-R foam<br>plug (no NRR): an exemplary combination y, monitoring video displays are located in the<br>susing the Baltimore Therapeutic Equipment<br>molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem provided for finger ivity; monitoring video displays are located in the<br>molded polymer arrest end a third consideration of the Baltimore Therapeutic Equipment<br>molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii towar

(1) Bilsom UF-1 Universal Earmuff (NRR = 25 in conchal and tragal areas of the ear and were<br>over-the-head position): a basic foam cushion too uncomfortable to wear the canal cans **e** 1. An occluded subject performing a work task activity; monitoring video displays are located in the simulator.<br>
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Simulator.<br>
Simulator schemes the position activity, one of six activities using the Baltimo Early the contained subject performing a work task activity; monitoring video displays are located in the Simulator.<br>
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Simulator.<br>
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the inserted the particular energy of the levels of each indepe Triable) being donned and worn under all<br>
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tions (within-subjects variables). A discuss-<br>
the inserted dipend form provided for f ble) being domed and worm under all molecul polymer earplug with three hemi-<br>
combinations of fitting and activity con-<br>
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in graps during interaction Bigian paid tensor that<br>
f combinations of fitting and activity con-<br>spectrating the interest interest into the correlation for the line of the levels of each independent vari-<br>of the levels of each independent vari-<br>(4) Combination: Bitom muff ove In the mestre of the heat of pain caused of pain cause in the mestre of the check of celests of each independent vari-<br>
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is trivity; monitoring video displays are located in the trivities using the Baltimore Therapeutic Equipment<br>molded polymer earplug with three hemispherical flames of decreasing radii toward<br>the inserted itip end (stem provid in the experiment probability; monitoring video displays are located in the trivities using the Baltimore Therapeutic Equipment spherical flanges of decreasing real it toward the inserted tip end (stem provided for finger nativity; monitoring video displays are located in the trivities using the Baltimore Therapeutic Equipment<br>spherical flages of decreasing radii toward<br>the inserted flages of decreasing radii toward<br>the inserted tip end (st nativity; monitoring video displays are located in the trivities using the Baltimore Therapeutic Equipment<br>molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem pro nationity; monitoring video displays are located in the trivities using the Baltimore Therapeutic Equipment<br>molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem pr tivities using the Baltimore Therapeutic Equipment<br>molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem provided for finger-<br>tip grasp during insertion)<br>(4) Combin molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem provided for finger-<br>tip grasp during insertion)<br>(4) Combination: Bilsom muff over E-A-R foam<br>plug (no NRR): molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem provided for finger-<br>tip grasp during insertion)<br>(4) Combination: Bilsom muff over E-A-R foam<br>plug (no NRR): molded polymer earplug with three hemi-<br>spherical flanges of decreasing radii toward<br>the inserted tip end (stem provided for finger-<br>tip grasp during insertion)<br>(4) *Combination: Bilsom muff* over *E-A-R foam*<br> $plag$  (no NR spectral tanges of decreasing radio towards<br>
the inserted tip end (stem provided for finger-<br>
tip grasp during insertion)<br>
(4) combination: Bilsom muff over E-A-R foam<br>
plug (no NRR): an exemplary combination<br>
protector f doff. A) Combination: Bilsom mulf) over E-A-R foam<br>plag (no NRR): an exemplary combination<br>protector for use in ambient noise levels<br>where "double" protection is needed (no NRR<br>is specified because the combined attenua-<br>tion is play to the "double" protector for use in ambient noise levels<br>where "double" protector is needed (no NRR<br>is specified because the combined attenua-<br>tion is less than the arithmetic sum of the in-<br>dividual protector attenu

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